EPA-905/3-79-001

PHYTOPLANKTON ASSEMBLAGES OF THE NEARSHORE ZONE OF SOUTHERN LAKE MICHIGAN

by

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Grant R005337 01

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ABSTRACT

Phytoplankton samples from nearshore stations along the Indiana coast of Lake Michigan were analyzed to determine the composition and seasonal abundance of phytoplankton populations in this region. Occurrence patterns of major populations and population groups were inspected to detect unusual patterns which might be indicative of particular inputs to this region of Lake Michigan. As might be expected in a local inshore region where physical mixing and advection processes are relatively intense, phytoplankton distribution is highly variable. The largest general effect noted is a continuing increase in groups other than diatoms, apparently as a result of silica depletion resulting from phosphorus enrichment. The singular exception to this trend is the abundant occurrence of *Cyclotella comensis*, a diatom which has only recently become abundant in Lake Michigan and which can apparently tolerate very low silica levels. An effect more specific to the region is the atypically high abundance of members of the diatom genus *Nitzschia* during some sampling periods. High abundance of these organisms is often associated with organic nitrogen and ammonia inputs, and this appears to be the case in the Indiana nearshore region of Lake Michigan. Occasional occurrences of populations such as *Thalassiosira* sp. and *Skeletonema* spp. were also noted in the samples. These appear to be associated with isolated water masses and may be indicative of local areas of high conservative ion input. It should be noted that the thermal bar period, when the effects of conservative ion loadings might be expected to be most intense, was not represented in the samples examined. Another characteristic of the phytoplankton assemblages in the Indiana nearshore region is the high abundance of microflagellates, especially

organisms which apparently belong to the Haptophyceae or Prasinophyceae. Although these organisms are known to be abundant in areas of the Great Lakes which are substantially perturbed, and are apparently generally increasing in Lake Michigan, little is known about their specific ecology due to methodological difficulties in identification. Further research should be devoted to this topic.

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ACKNOWLEDGMENTS

We would like to thank Ted B. Ladewski for his assistance on the computer analysis used in this study. We would also like to acknowledge the U.S. Environmental Protection Agency for collecting the samples and performing the physico-chemical analyses.

INTRODUCTION

Compared to most areas of the Great Lakes, the southern shoreline region of Lake Michigan has enjoyed a relatively long period of study. Qualitative records of phytoplankton and benthic algal occurrence extend back into at least the 1870's. The history of these investigations has been reviewed by several authors, including Stoermer and Yang (1969). One of the more interesting aspects of this historical perspective is that the majority of the studies undertaken, including some of the very earliest, were in response to some perceived pollution problem of the day. This long succession of practically oriented studies has provided a record of extensive population replacement in phytoplankton communities, and some indication of change in absolute abundance of populations and modification of seasonal population dynamics.

Although there is little doubt that the major factor driving algal succession in Lake Michigan is phosphorus pollution due to both its primary and secondary effects, there are undoubtedly other effects which are partially masked by this overriding factor. Perhaps the least understood of these is the effect or effects of increasing conservative ion abundance. It has long been recognized that there are striking differences in the algal floras in waters of different salinities. It is also very apparent that many of the algal populations which have invaded the Great Lakes during the past few decades are characteristically found in high salinity environments. This particular modification is, of course, true not only of algal populations but of consumer organisms as well. The actual physiological and/or ecological mechanisms operating have not been satisfactorily determined. It is clear, however, that further modification of the indigenous biota is highly undesirable, and that if

conservative ion contamination is a major contributory factor, it poses a very serious problem due to the very long residence times of the Great Lakes and the difficulty in controlling sources.

At the present time the most pronounced and complicated effects of multiple loadings occur in the nearshore waters. This zone is also the region of most intensive physical effects. Local and transient advection regimes may cause gross variations in the dispersion of pollutants entering the lake and, as would be expected, the influence of these materials on the algal flora may be highly variable. These regions may thus show a long term statistical trend in population modification but, at any given time, these trends may be submerged by local effects of transient intensity.

The present project deals with a limited area of Lake Michigan along the Indiana coastline. This region lies within the area of Lake Michigan which has been extensively modified by factors which affect phytoplankton occurrence and abundance. Several qualitatively different local sources are present, and the effect of these sources on phytoplankton composition and abundance are of special interest because adjacent regions of the lake are intensively utilized for both recreational purposes and as a source of potable water.

The primary objectives of the project, which is part of a more comprehensive investigation, are the following:

1. To determine the composition and abundance of the phytoplankton flora in comparison with past conditions to the extent that they are known, and provide firm documentation for comparison with future studies;

2. To determine if there are occurrence patterns of specific phytoplankton physiological group populations which may reflect the effects of specific sources;

3. To determine if distribution patterns in the phytoplankton are correlated with particular chemical or other biotic parameters which may indicate a cause-effect relationship.

MATERIALS AND METHODS

The sampling array utilized in this study is shown in Figure 1. Sampling was conducted on 11 June, 20 August, and 24 September, 1977. Four transects were analyzed with stations located 1/4, 1/2, 1, and 2 miles offshore. The eastern-most transect did not have a 2 mile station. For each station a 2 m and bottom sample were analyzed. All samples were collected by the U.S. Environmental Protection Agency.

All samples for phytoplankton population analysis were taken as 250 ml splits of the original 5-liter Niskin Bottle cast. These subsamples were fixed with a Lugols solution and stored. For subsequent analysis, the sample bottles were agitated and a 50 ml aliquot was removed. Material was concentrated by filtration onto 25 mm "AA" Millipore filters, partially dehydrated through an ethanol series, and embedded in clove oil. Prepared filters were mounted on a 50 x 75 mm glass slide and covered with a 43 x 50 mm #1 cover glass. Preparations were kept in a horizontal position and allowed to dry for approximately two to four weeks, during which time embedding medium lost by volatization was periodically replaced. When the filter was completely cleared, the edges of the cover glasses were sealed with paraffin.

Slides were analyzed by visual counts of phytoplankton cells present using Leitz Ortholux microscopes fitted with fluorite oil immersion objectives with a nominal Numerical Aperature of 1.32. Magnification used for identification and enumeration was approximately 1200 X. Population estimates given are the average of two 10 mm radial strips counted. Effective filtration diameter in the filtration apparatus used is 20 mm.

Raw counts were transformed to computer format on punched cards. Computer

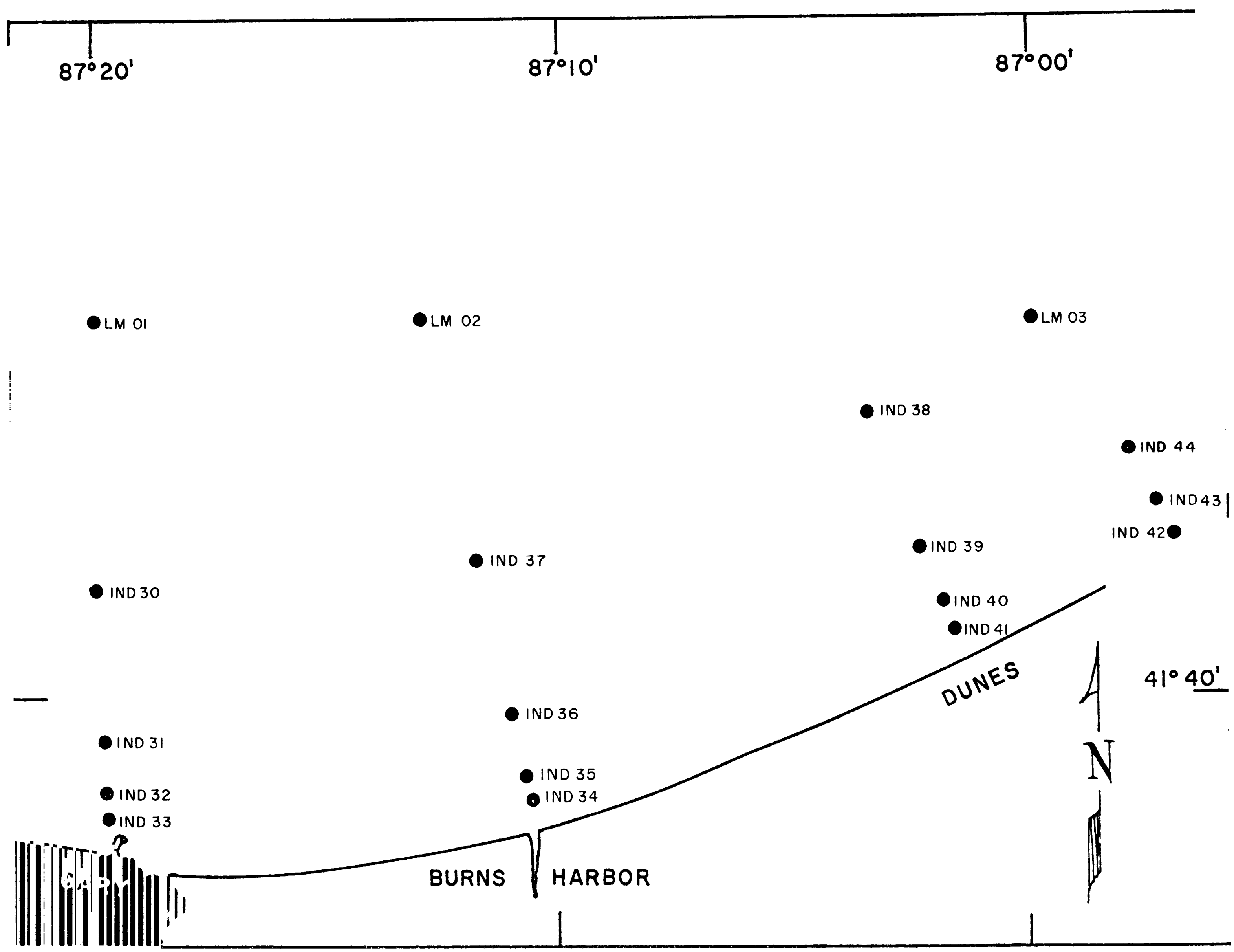

FIG. 1. Sampling station locations; southern Lake Michigan, 1977.

data summaries are available for all samples counted (see Stoermer and Kreis, in press). Summaries include estimates of absolute frequency and associated error, and an estimate of relative abundances for individual taxa as well as major algal divisions. Assemblage parameters calculated included an estimate of total phytoplankton abundance and a measure of error associated with the estimate, an estimate of assemblage diversity (H), and an estimate of the evenness component of the calculated diversity. Summary information is stored on magnetic tape and is available for further data anlysis.

Various physico-chemical analyses were conducted by the EPA at the time the samples were collected, and they provided this information to us. Contour plots for these data are presented in Appendix Figures 1-33.

RESULTS

OVERALL ABUNDANCES OF MAJOR ALGAL GROUPS

Relative and absolute average abundances of major algal groups for a given cruise are presented in Table 1. Highest overall densities were attained by blue-green algae and diatoms, with greens, chrysophytes, and cryptomonads, secondarily important. The undetermined category consists almost entirely of microflagellates which presumably belong to the Haptophyceae (Stoermer and Sicko-Goad, 1977; Sicko-Goad, Stoermer, and Ladewski, 1977). Total absolute abundances for the three cruises are presented in Figure 2. A total of 288 taxa were identified and recorded. The average total density for all samples was 4420 cells/ml, ranging from 844 to 12,078 cells/ml.

In June, depending on the station, either blue-green algae, diatoms, or haptophytes were the major group present. At Gary Harbor, haptophytes were dominant at the two offshore stations, with diatoms dominant nearshore. At Burns Harbor, diatoms were the dominant group at all stations except the 1/2 mile station, where blue-green algae dominated the assemblage. At the Indiana Dunes transect, diatoms were the most numerous at the near- and offshore stations, with haptophytes dominant at the 1/2 mile and 1 mile stations, composing 57 and 50% of the total community respectively. Along the eastern-most transect near Michigan City, diatoms were dominant at the two nearshore stations, averaging 55% of the population, with blue-green algae dominant at the 1 mile station, composing about 38% of the community. Over all 15 stations in June, diatoms averaged 35.8% and blue-green algae averaged 18.6% of the total phytoplankton.

TABLE 1. STATISTICAL SUMMARY OF MAJOR ALGAL GROUPS IN SOUTHERN LAKE MICHIGAN, 1977.

	June		August		September	
	Ave. Relative Abundance %	Ave. Cells/ml	Ave. Relative Abundance %	Ave. Cells/ml	Ave. Relative Abundance %	Ave. Cells/ml
Blue-greens	18.60	423.49	51.55	2038.82	50.48	1683.05
Greens	8.01	168.11	17.37	697.15	7.76	249.93
Diatoms	35.82	780.50	17.33	680.53	23.42	757.60
Chrysophytes	8.52	224.38	1.32	52.78	1.92	59.48
Cryptomonads	4.99	122.87	3.41	136.69	6.64	207.91
Dinoflagellates	0.69	13.26	0.36	14.10	0.18	5.73
Undetermined	22.59	581.26	5.38	213.77	2.61	82.52

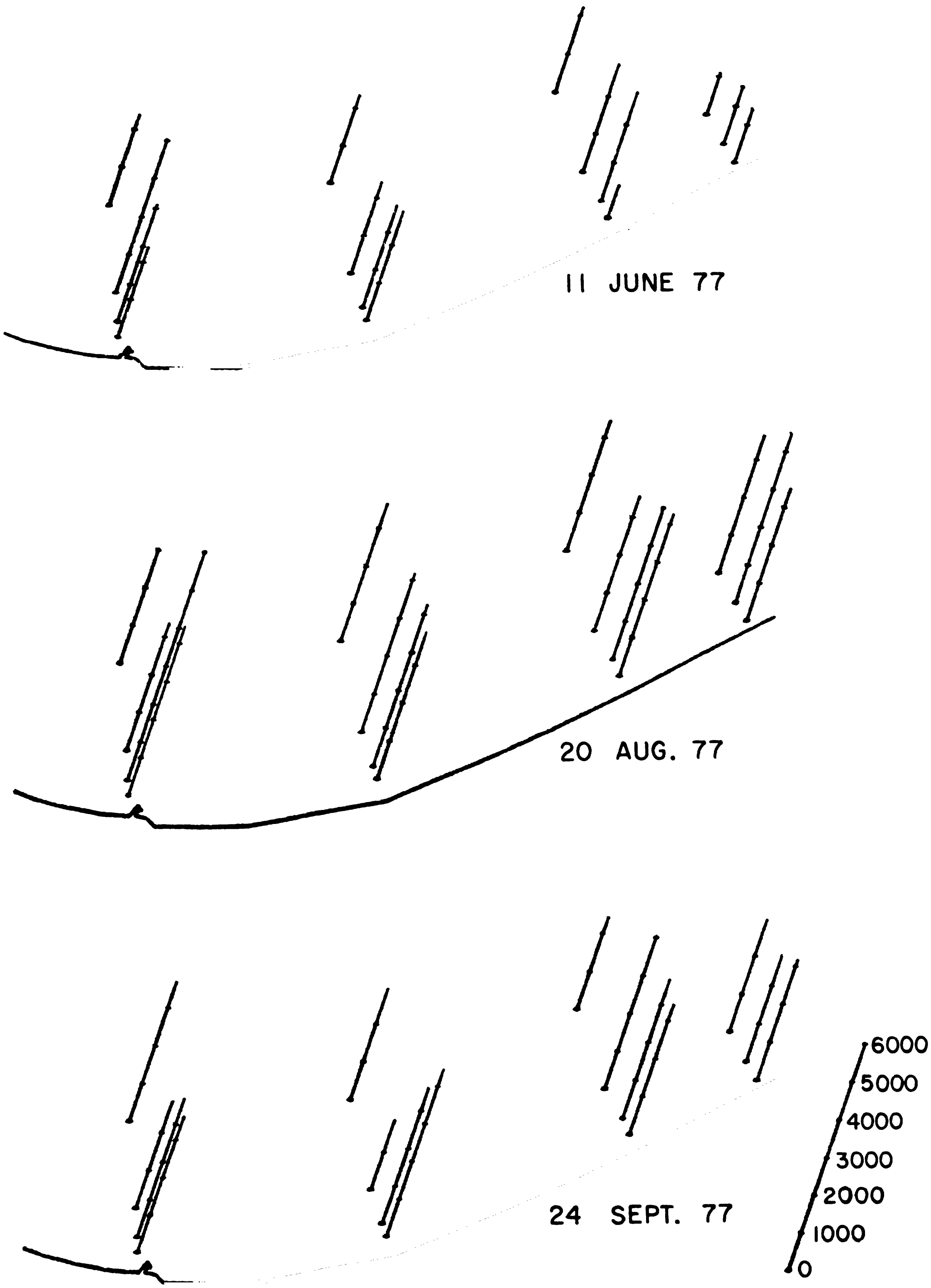

FIG. 2. Seasonal Distribution and Abundance Trends of the Total Phytoplankton Assemblage.

In the August sampling period, blue-green algae were the dominants at all stations along all four transects. They ranged from a low of 33% of the total algal assemblage at station 33 to 67% at station 37. The diatom component ranged from 9 to 28% of the total assemblage. The green algae composed approximately the same proportion of the community as did the diatoms, ranging from 12 to 28%.

In September, blue-green algae maintained their dominance. Only at the 1 mile station off Burns Harbor and Gary Harbor did the diatoms dominate. Over all 15 stations, blue-green algae averaged 52% (Table 1) of the total community and reached a maximum of 58% at the 1 mile station at Indiana Dunes. Diatoms composed 23% of the total and were more numerous at the western-most two transects, possibly as a response to the higher silica values.

REGIONAL AND SEASONAL TRENDS IN ABUNDANCE OF SELECTED TAXA

Bacillariophyta

Asterionella formosa Hass. (Fig. 3)

This species occurs in all regions of the Great Lakes, and appears to be eurytopic. In southern Lake Michigan, it seemed to be fairly sensitive to silica levels. In June, it was found in higher numbers offshore and along the Gary Harbor transect, where all silica values were above 0.30 mg/l (Appendix Fig. 22). In August, it was present in low densities, not over 30 cells/ml. It was found at its maximum at the 1/2 mile station off Burns Harbor, with a silica value of 0.58 mg/l (Appendix Fig. 23). This large silica value was probably the result of an isolated "slug" of river water derived from Burns

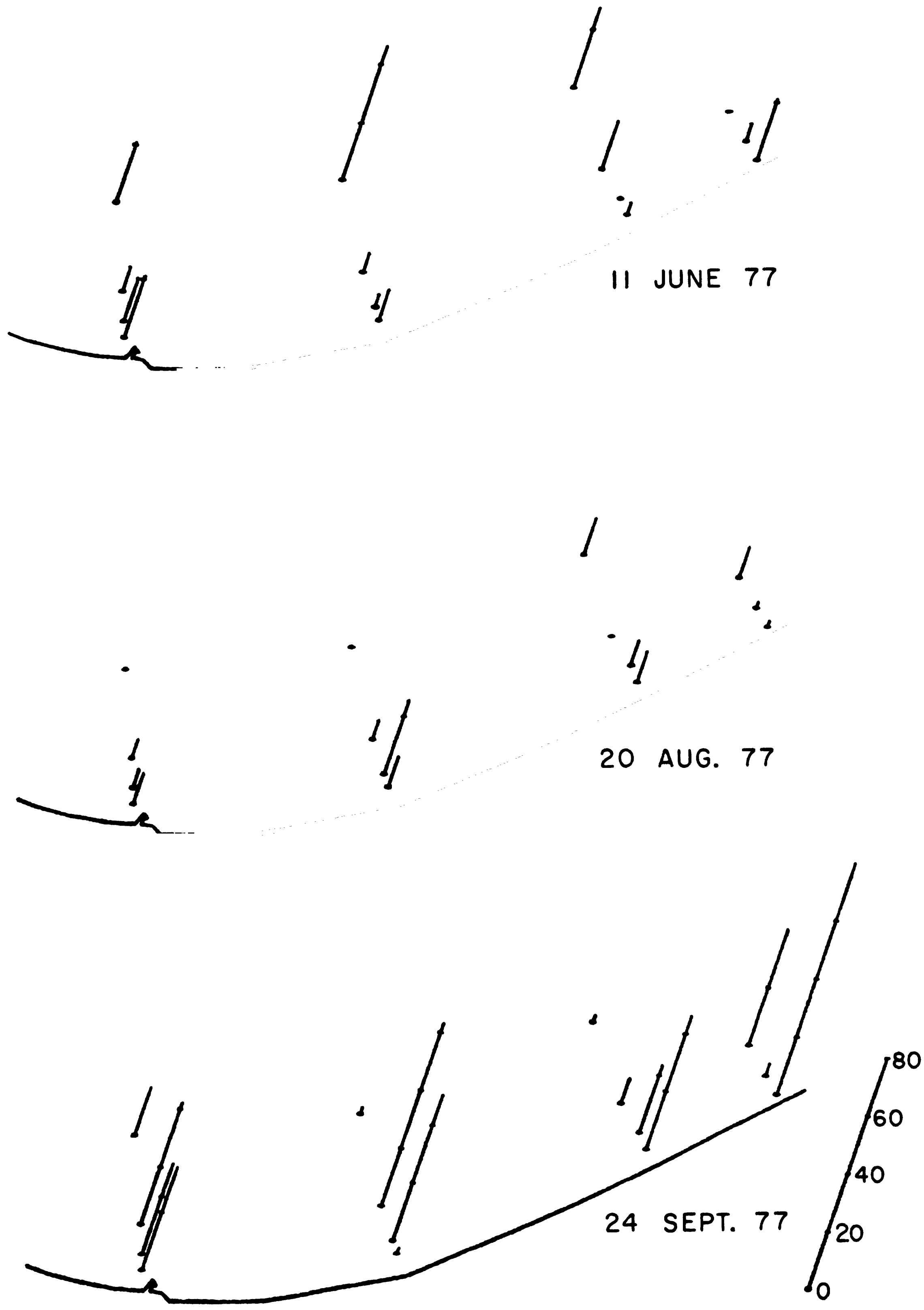

FIG. 3. Distribution of _Asterionella formosa_.

Harbor and entrained in a local circulation gyre. The effect of this "slug" was also noted in various other species examined. Highest abundances of *A. formosa* were present in September, probably related to the higher silica values present in this month (Appendix Fig. 24).

Cyclotella comensis (Grun.) V.H. (Fig. 4)

This species is a relatively recent introduction into Lake Michigan, and its ecological affinities are not well known. In Saginaw Bay in 1974, it appeared in bloom quantities in August, and was still abundant into October (Stoermer and Kreis, in press). They also noted that it was able to tolerate very low levels of silicon. In southern Lake Michigan, a similar seasonal effect was present. It was found in very low numbers in June, but increased substantially in the August and September sampling periods. Abundances of this species appeared to be highest near shore and along the Gary Harbor and Burns Harbor transects, possibly displaying a high tolerance for more perturbed areas. Analysis of variance determined that, in August, densities were significantly lower (.05 level) at the offshore stations on each transect than at the three nearshore stations. Additionally, significant positive correlations at the .01 level were found with NO_3, NH_3, and conductivity in both August and September. However no such significant correlations were found with silica.

Cyclotella cryptica Reimann, Lewin, and Guillard (Fig. 5)

This species was originally described from a brackish-water habitat (Reimann *et al.*, 1963). Most of the records of its occurrence in Lake Michigan come from harbors and inshore areas subject to high chloride levels (Stoermer

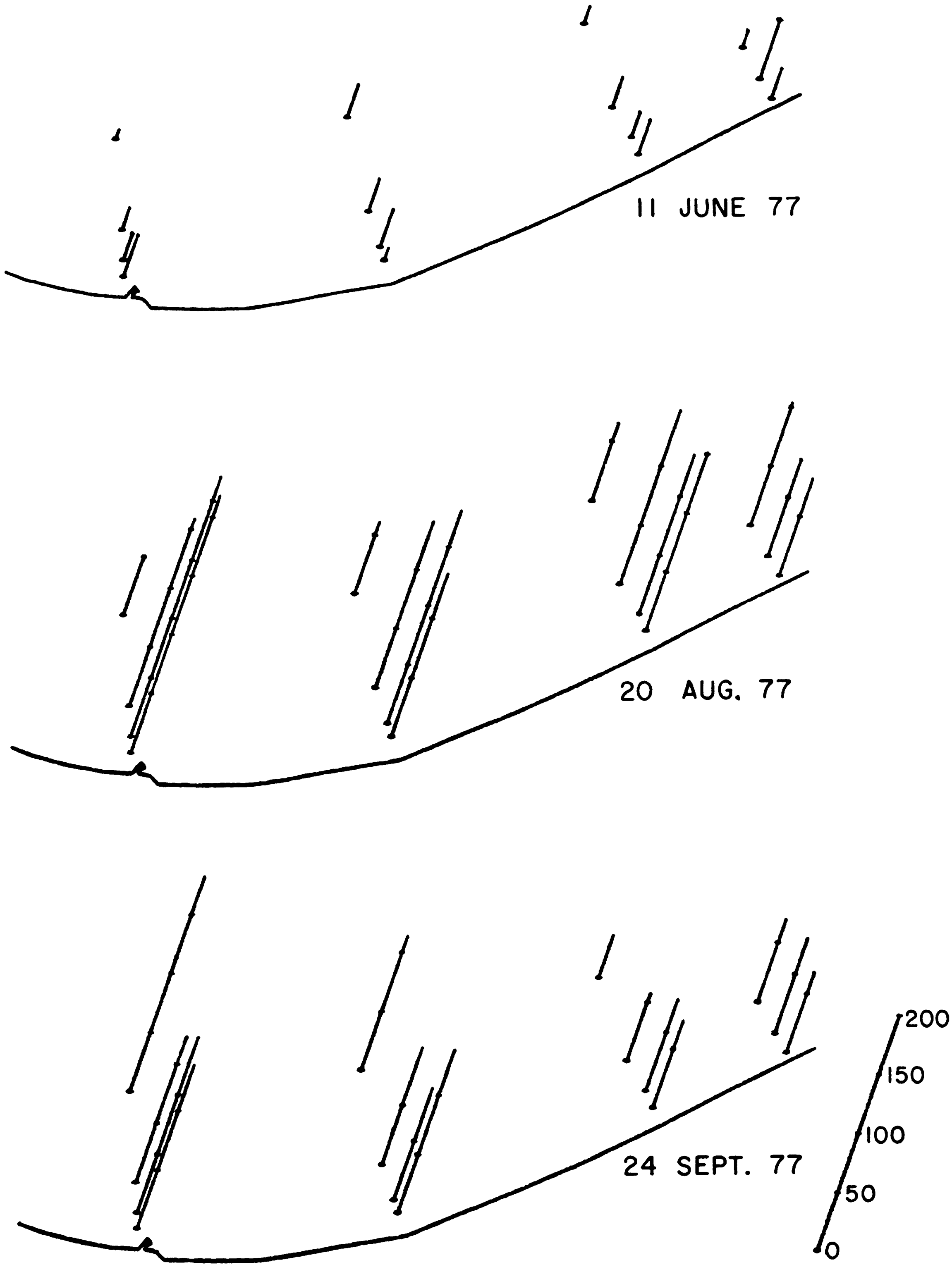

FIG. 4. Distribution of *Cyclotella comensis*.

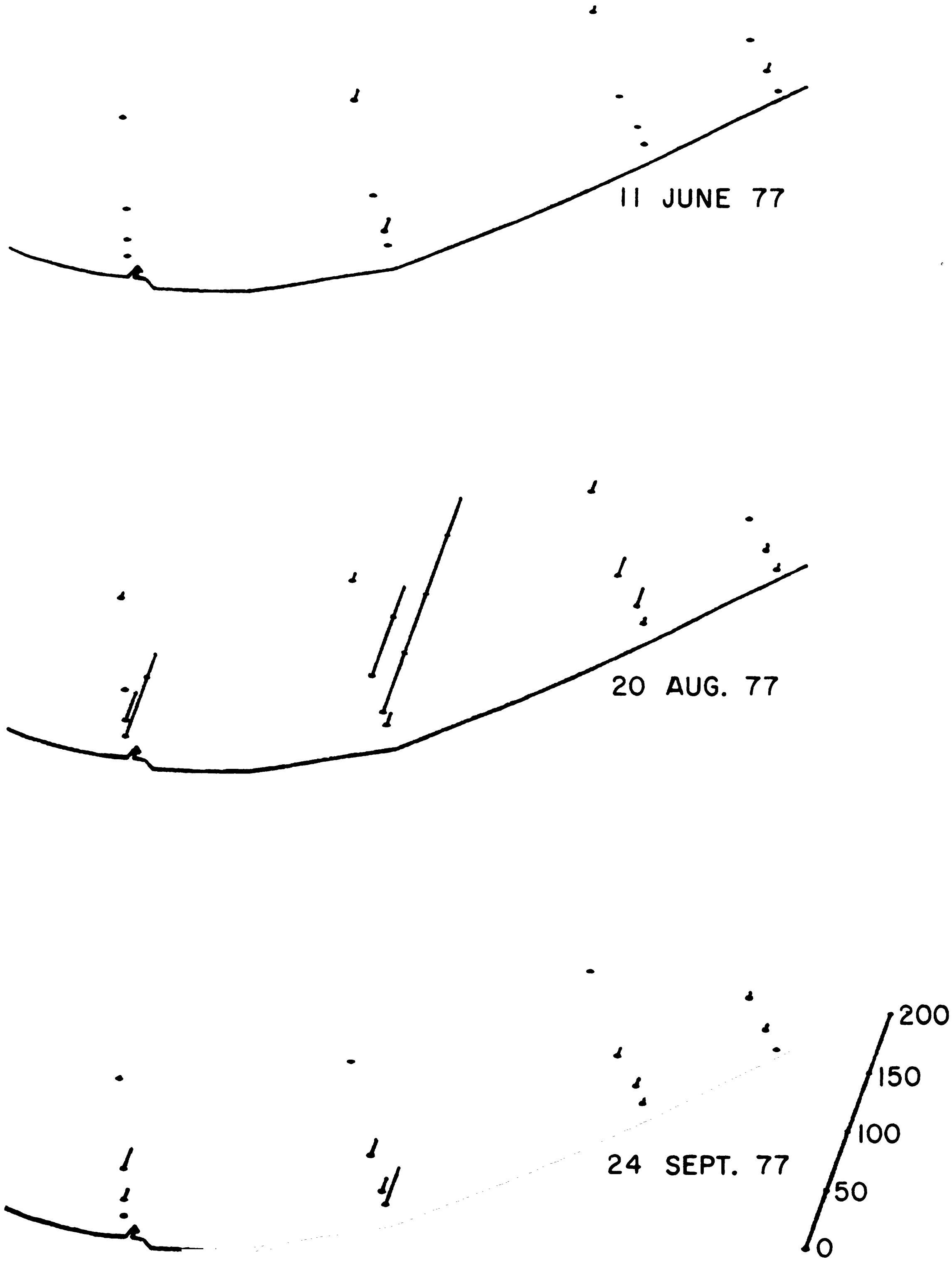

FIG. 5. Distribution of *Cyclotella cryptica*.

and Yang, 1969). In southern Lake Michigan, it was found in low numbers in June and September. However, in August, it was found in fairly high densities near shore along the Gary and Burns transects. A maximum density of 180 cells/ml was found at the 1 2 mile station at Burns Harbor, probably due to the presence of river water derived from the harbor. In August, *C. cryptica* was significantly correlated with conductivity, NO_3, SiO_2, and aerobic heterotrophs.

Cyclotella pseudostelligera Hust. (Fig. 6)

Populations of this species are usually found in eutrophied areas. Its range in the Great Lakes appears to be restricted to harbors and river mouths (Stoermer and Ladewski, 1976). It was present in southern Lake Michigan in low numbers in June and September. However, in August, it had a distribution similar to *Cyclotella cryptica*. A maximum density was found at the 1/2 mile station at Burns Harbor once again, where it appears that the river water is having a great effect on the makeup of the algal community. High numbers were also found at the 1 mile station at Burns Harbor, and the 1/4 mile station at Gary. Similar to *C. cryptica,* it also was found to be significantly correlated with conductivity, NO_3, SiO_2, and aerobic heterotrophs in August.

Cyclotella stelligera (Cl. & Grun.) V.H. (Fig. 7)

This species has been reported to be intolerant of high levels of eutrophication, and is usually removed from regions of the Great Lakes which have undergone extensive perturbation. Hohn (1969) reported that its abundance in Lake Erie has declined since the 1930's. In southern Lake Michigan, it was present in highest numbers in the August and September cruises. In August, the

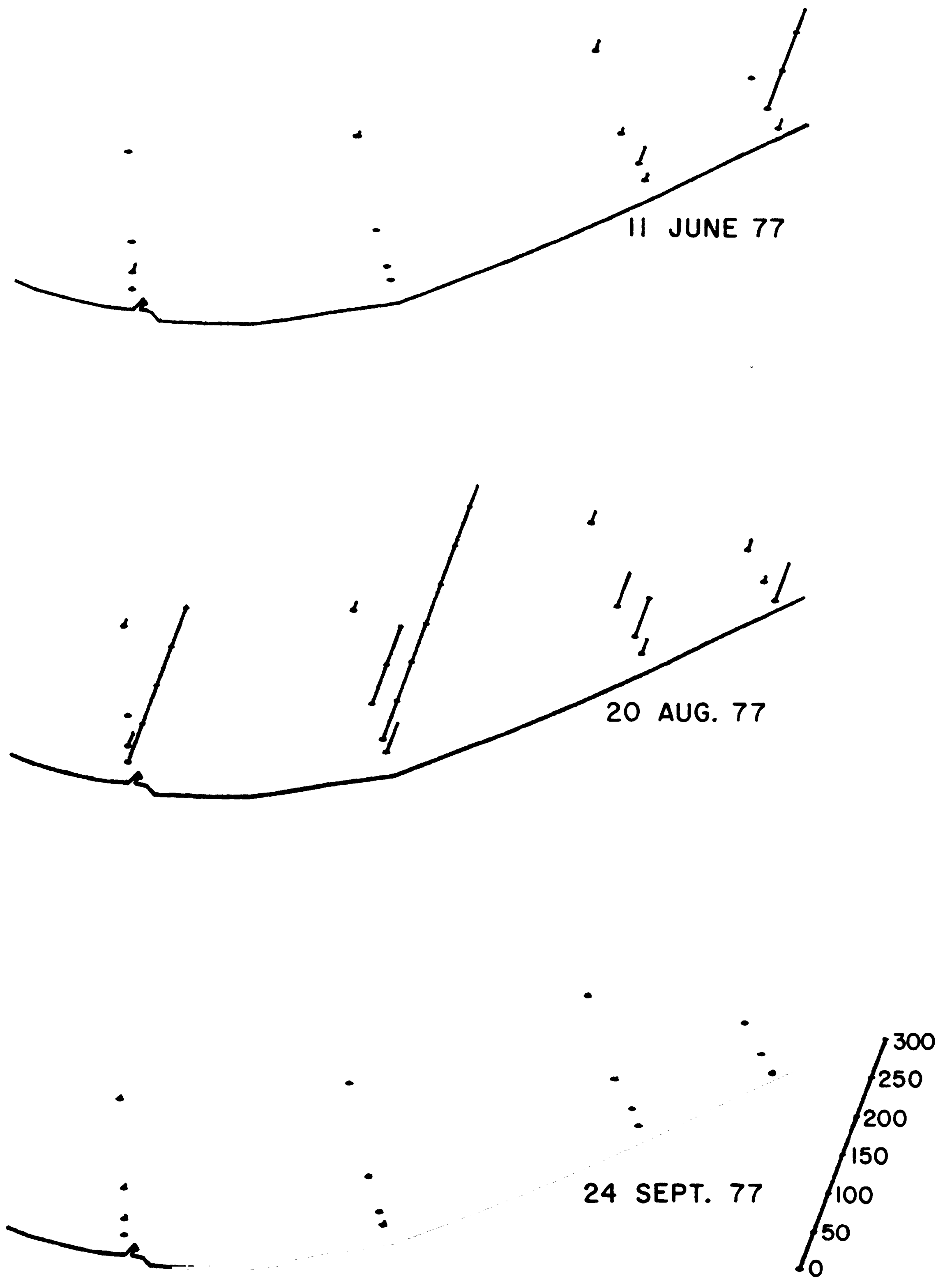

FIG. 6. Distribution of *Cyclotella pseudostelligera*.

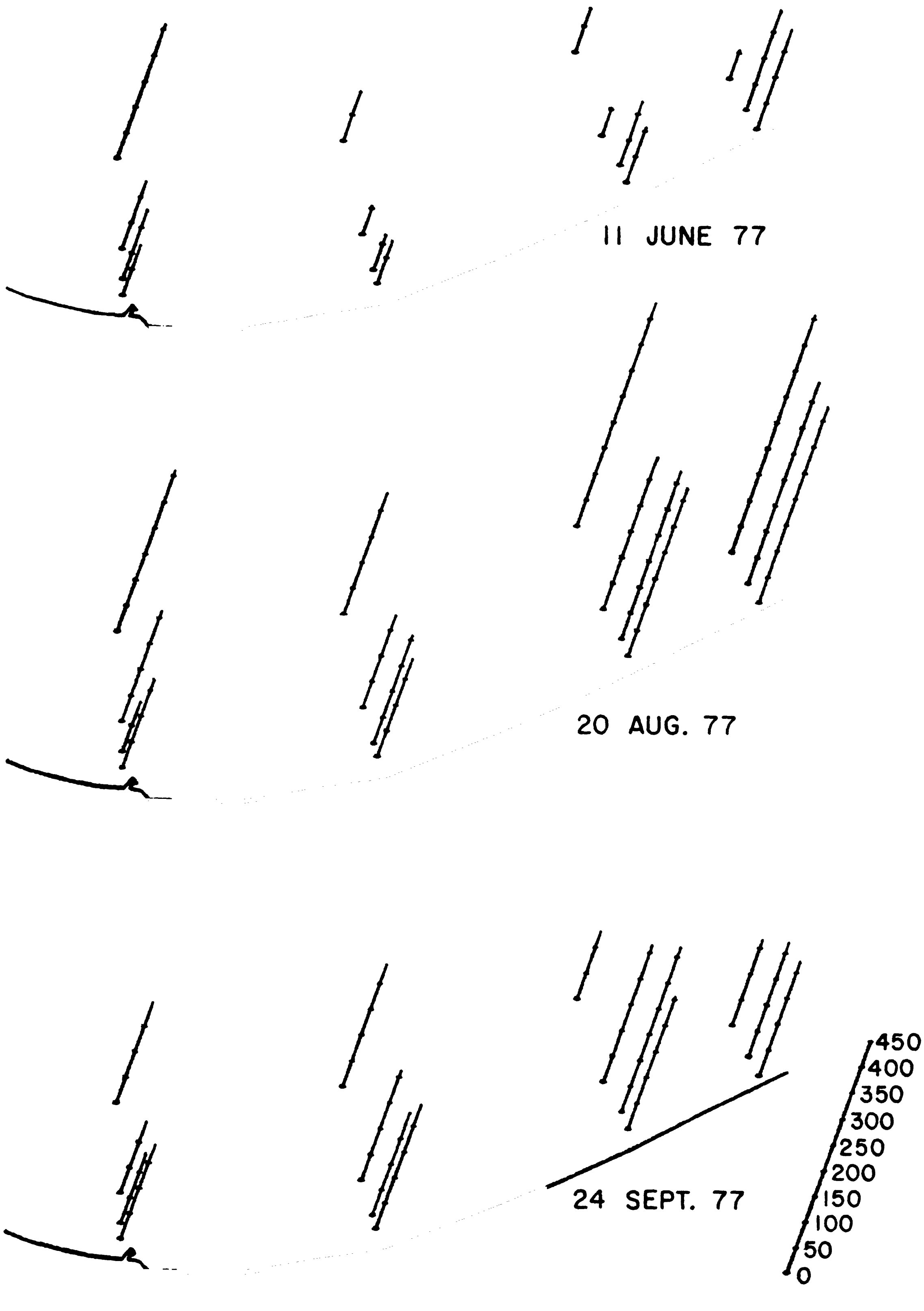

FIG. 7. Distribution of *Cyclotella stelligera*.

analysis of variance procedure demonstrated that, at the 5% level of significance, higher numbers were found at the less disturbed eastern-most two transects than at Gary or Burns Harbor. In June and September, no trends were apparent. No significant correlations were found for *C. stelligera* versus any physico-chemical parameter monitored for the three sampling dates.

Fragilaria crotonensis Kitton (Fig. 8)

This species is one of the most common plankton diatoms. It is present in all the Great Lakes, and can tolerate a wide range of ecological conditions. As in Saginaw Bay in 1974 (Stoermer and Kreis, in press) densities were lowest in August, with only isolated low level populations found. Highest densities were recorded in September, with a decreasing offshore trend apparent. In this month it exhibited a significant positive correlation at the .01 level with conductivity, NO_3, NH_3, and SiO_2. In June, densities were intermediate between August and September values, with no trends evident.

Nitzschia acicularis Wm. Sm. (Fig. 9)

This species is widely distributed in the Great Lakes. In southern Lake Michigan, in June, its distribution was erratic, although it was found in slightly higher numbers at the Burns Harbor transect. Populations declined to very low numbers in August, similar to the seasonal pattern observed in southern Lake Huron (Stoermer and Kreis, in press). Densities increased in September, attaining their highest values, with greatest abundances tending to be concentrated along the nearshore areas and the Gary and Burns Harbor transects. In September, significant positive correlations at the .01 level were found with conductivity, NO_3, NH_3, SiO_2, and aerobic heterotrophs.

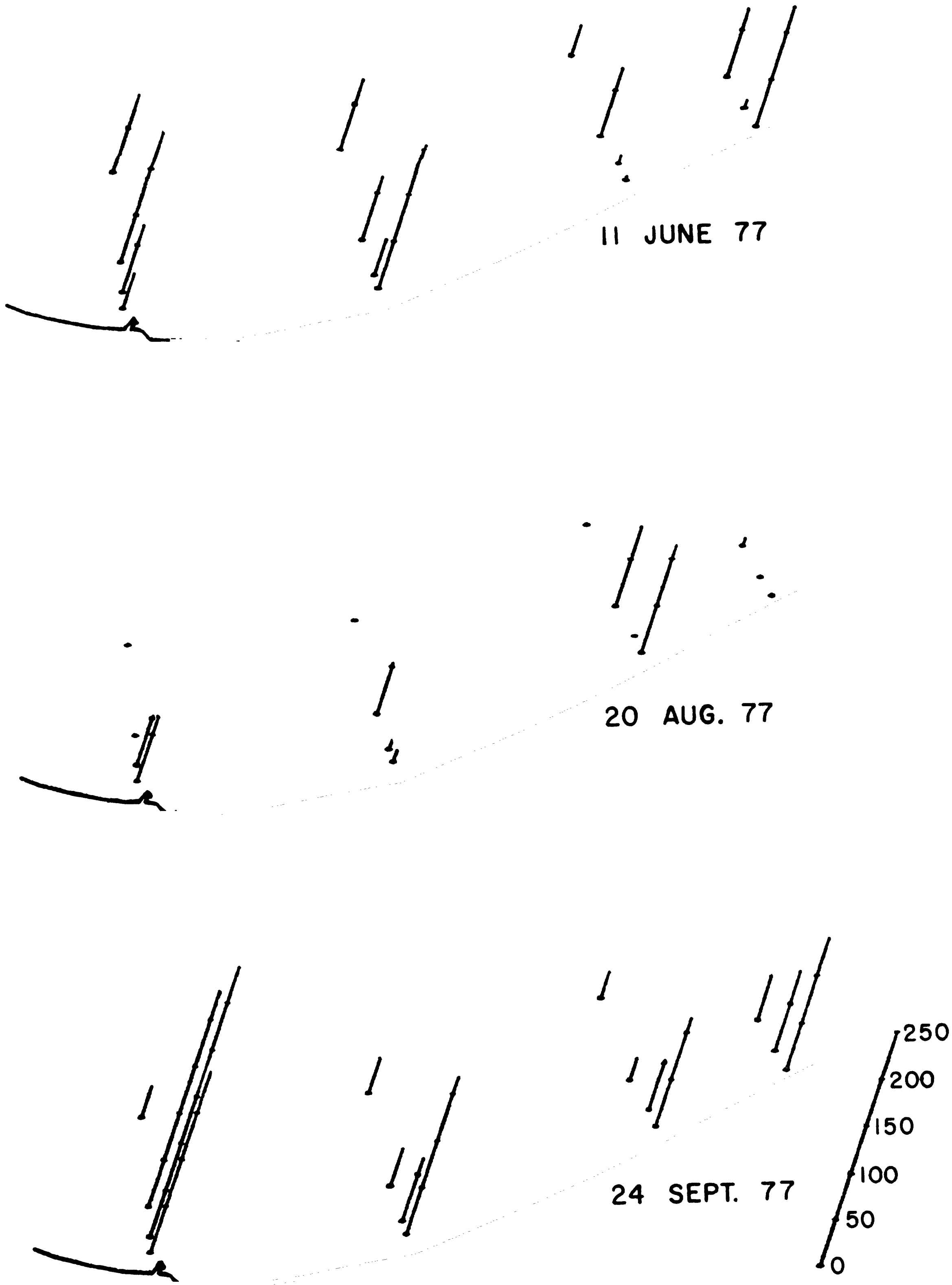

FIG. 8. Distribution of *Fragilaria crotonensis*.

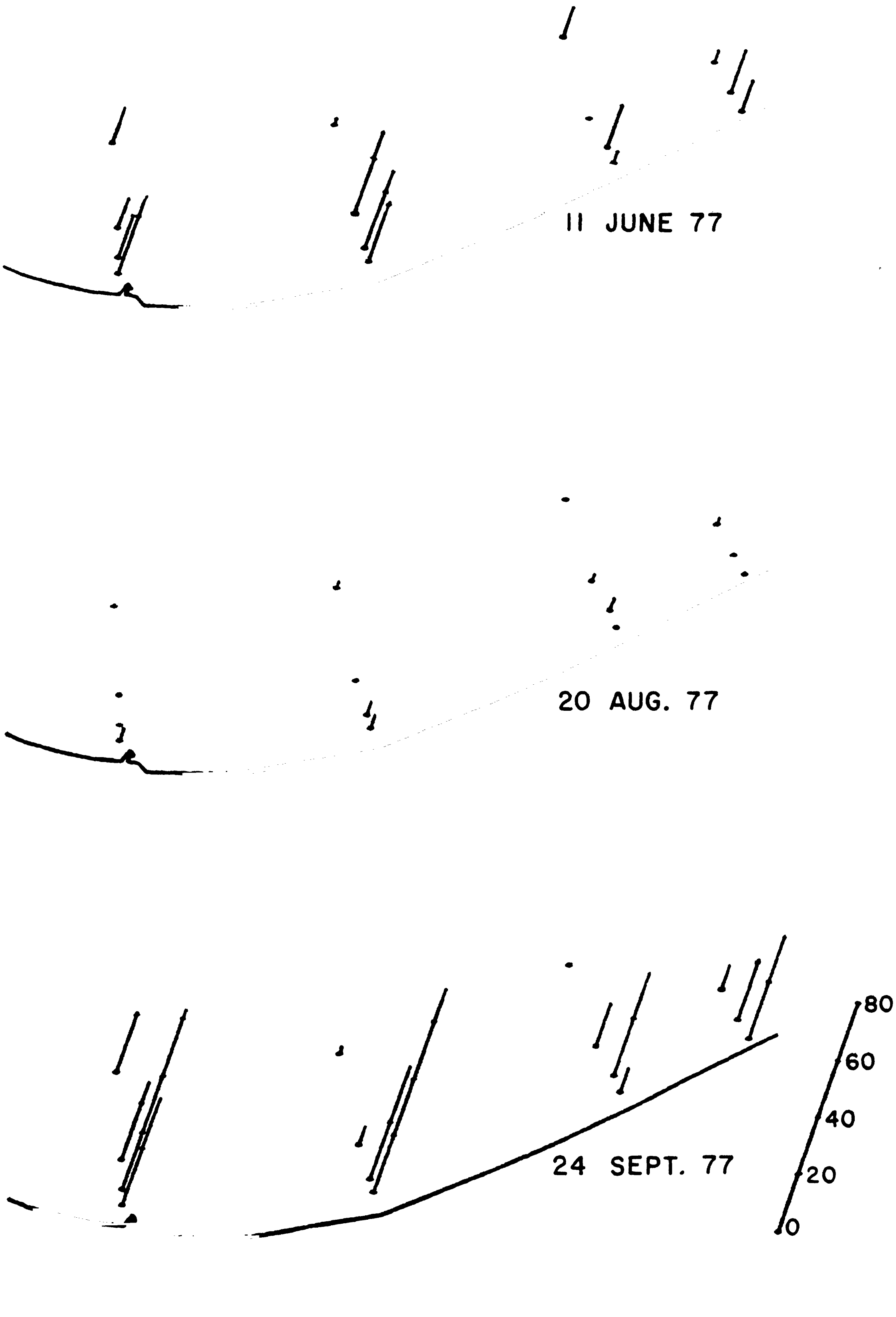

FIG. 9. Distribution of *Nitzschia acicularis*.

Nitzschia fonticola Grun. (Fig. 10)

This species has predominantly been recorded from nearshore localities in the Great Lakes (Stoermer and Yang, 1969). In June, its distribution was erratic, with no trends evident. Its numbers declined in August, and it was not present at all at the offshore stations. By September, it attained its highest densities. Like *N. acicularis* it demonstrated a preference for the nearshore regions and for the Gary and Burns Harbor transects. In September, it was found significantly correlated at the .01 level with NO_3, NH_3, and aerobic heterotrophs. Overall, its distribution appears to be fairly similar to *N. acicularis*, and it too displays a tolerance for polluted conditions.

Nitzschia palea (Kutz.) Wm. Sm. (Fig. 11)

Stoermer and Yang (1969) noted that most of the records for this species in Lake Michigan come from polluted harbors and river mouths. In this study, it reached its greatest abundance in June, and displayed definite affinities for the Gary and Burns Harbor regions. On this first cruise, it was found to be significantly correlated at the .05 level with NO_3 and NH_3. Its numbers decreased in August and September. Larger densities were found at the nearshore stations than at the furthest offshore station for all transects in the latter two months.

Stephanodiscus minutus Grun. (Fig. 12)

This species has been reported to be a winter dominant in mesotrophic to eutrophic lakes (Huber-Pestalozzi, 1942). In Lake Michigan, Stoermer and Yang (1970) noted that it becomes abundant in early spring collections from certain near and offshore localities. They also noted that it was more abundant in

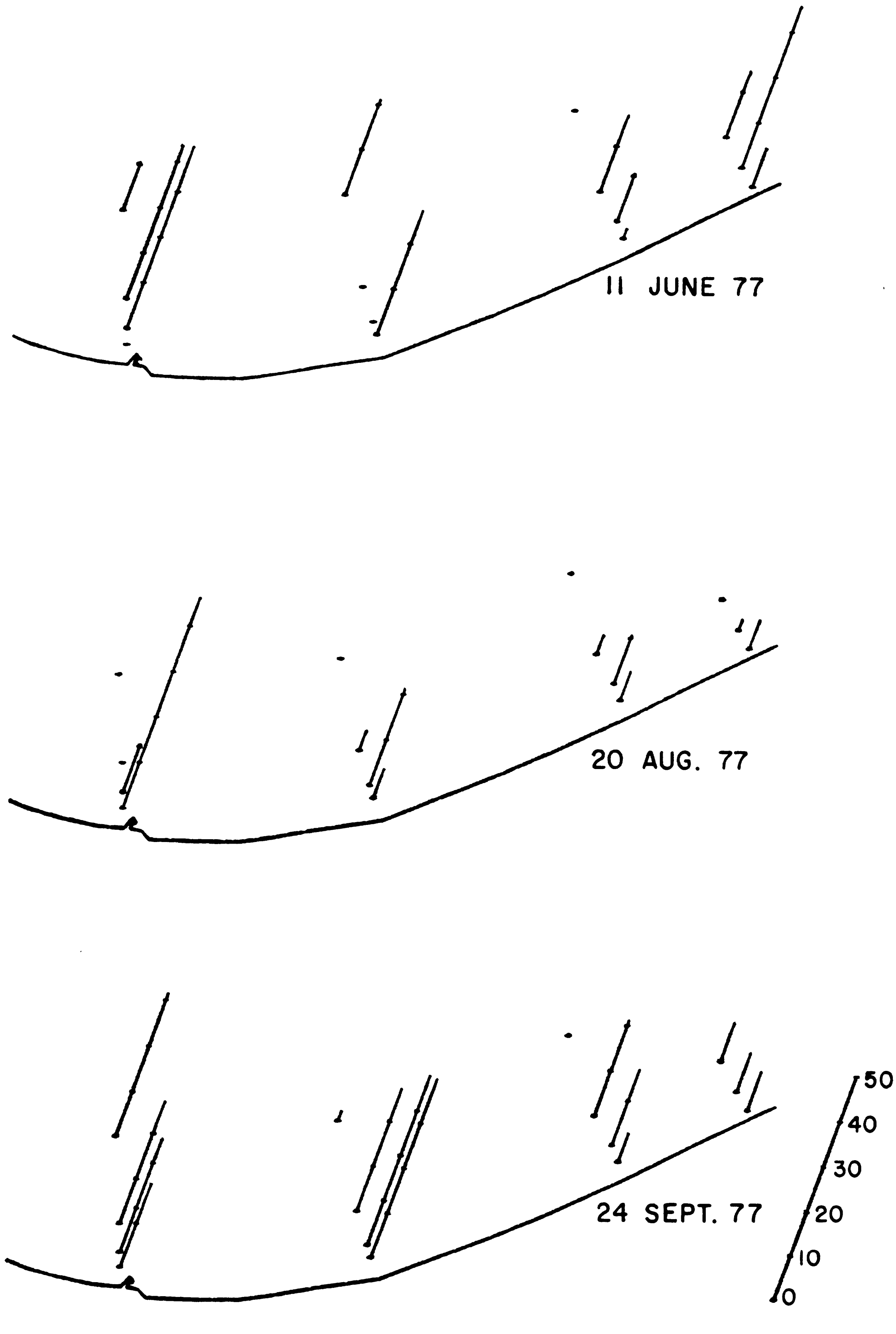

FIG. 10. Distribution of Nitzschia *fonticola*.

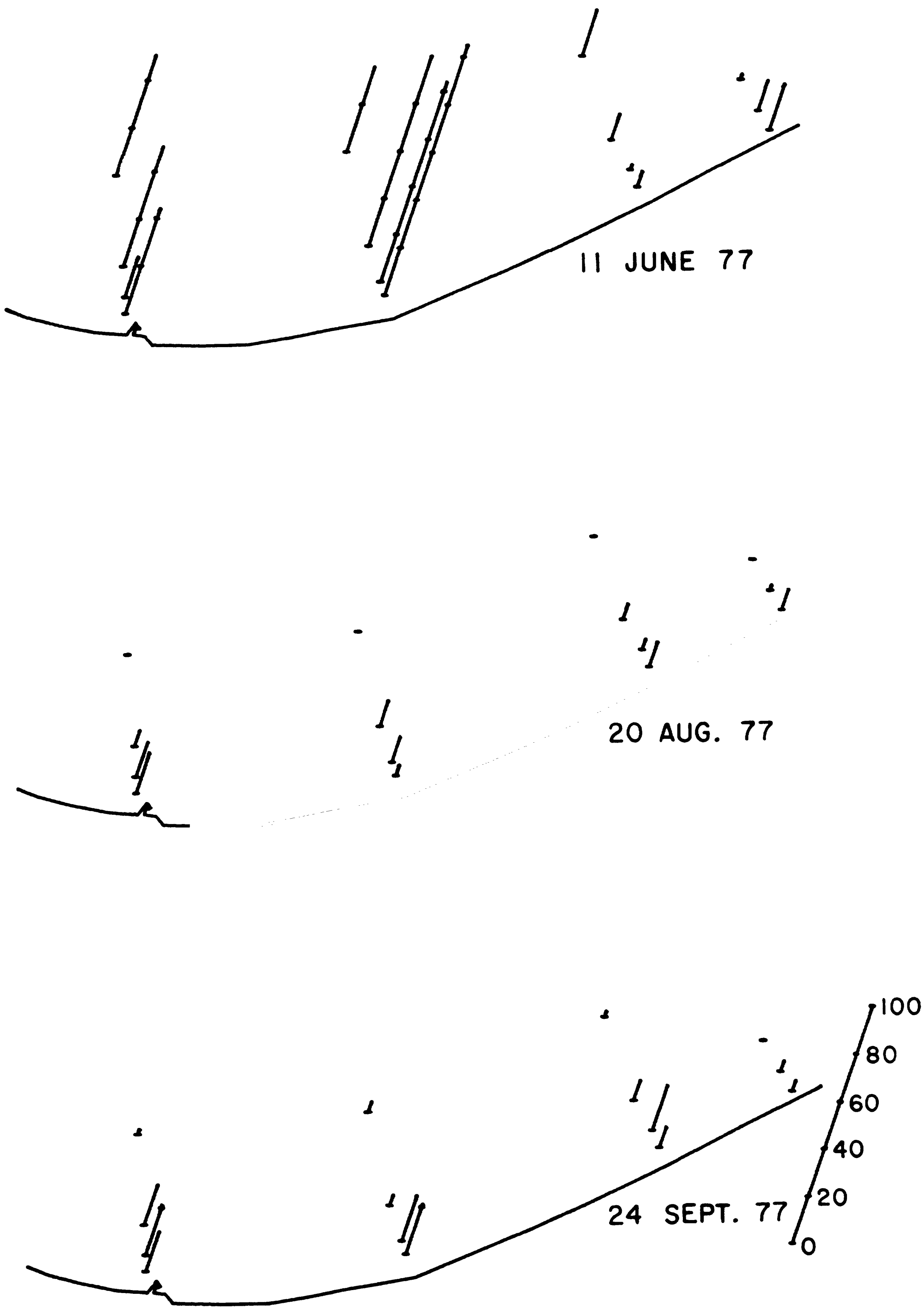

FIG. 11. Distribution of Nitzschia palea.

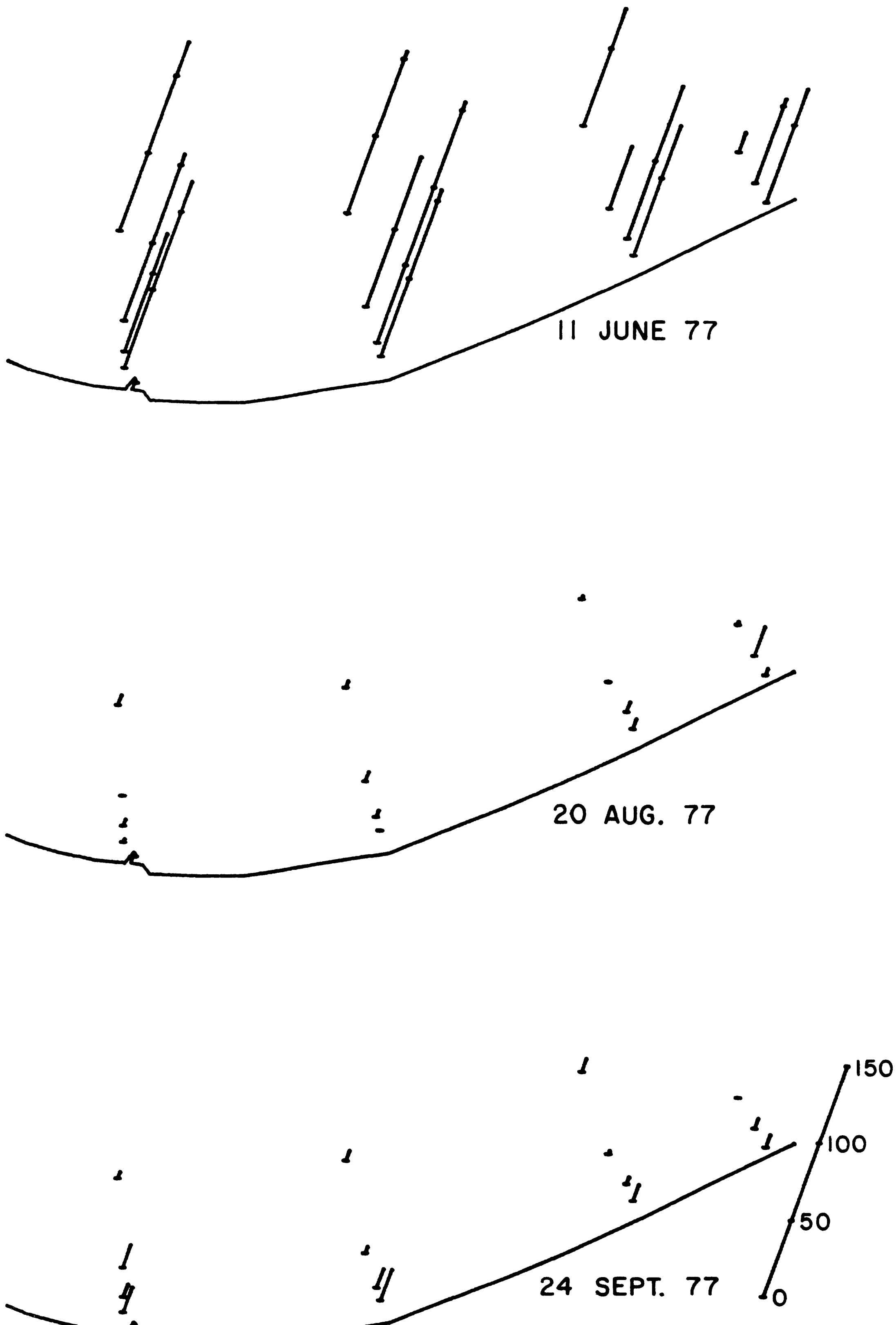

FIG. 12. Distribution of *Stephanodiscus minutus*.

1967 than 1964. In June, in southern Lake Michigan, this species was present in fairly high numbers, and displayed a preference for the more eutrophied Gary and Burns Harbor regions. By August and September, its numbers declined drastically and it was present in very low numbers at a few stations.

Synedra filiformis Grun. (Fig. 13)

This species has been recorded mainly from offshore regions in Lake Michigan, and Stoermer and Kreis (in press), regard it as one of the characteristic species of the offshore phytoplankton in the upper Great Lakes. However, Cleve-Euler (1953) noted that it can tolerate brackish water. In September, it was found in greatest abundance in the polluted Gary Harbor region, and it decreased moving east to Michigan City. Its abundance was also found to correlate highly with conductivity, NO_3, and NH_3 at the .01 level. Its numbers were very low in June and August at all stations.

Tabellaria flocculosa var. *linearis* Koppen (Fig. 14)

This species was present at scattered stations in June. By August, its numbers declined, similar to the occurrence pattern noted in southern Lake Huron (Stoermer and Kreis, in press). In September, large populations occurred at the two nearshore stations at Gary Harbor (Fig. 14). Generally, in September, offshore densities were lower than they were near shore. It also exhibited significant positive correlations with NO_3 and SiO_2 at the .01 level in September.

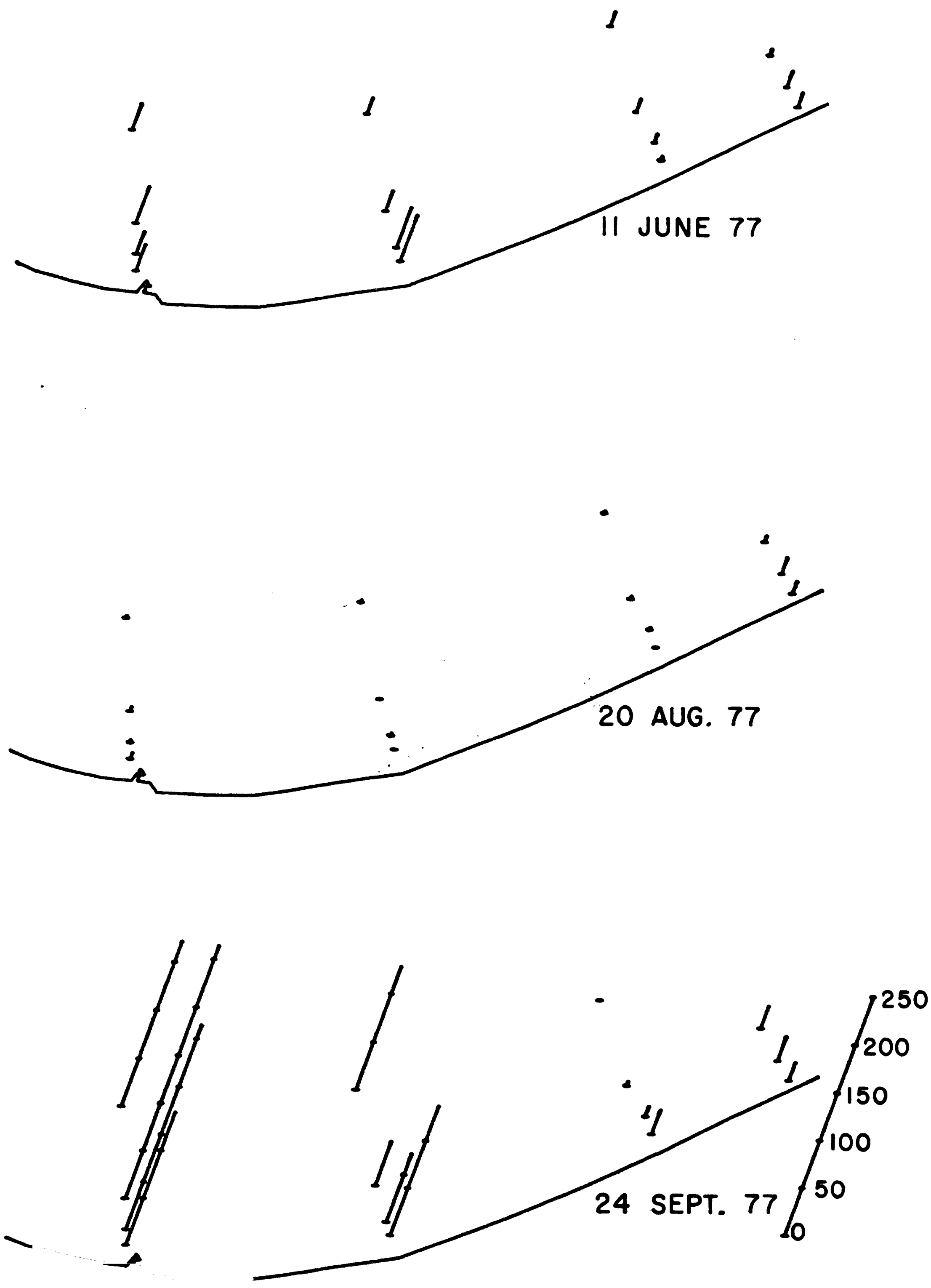

FIG. 13. Distribution of *Synedra filiformis*.

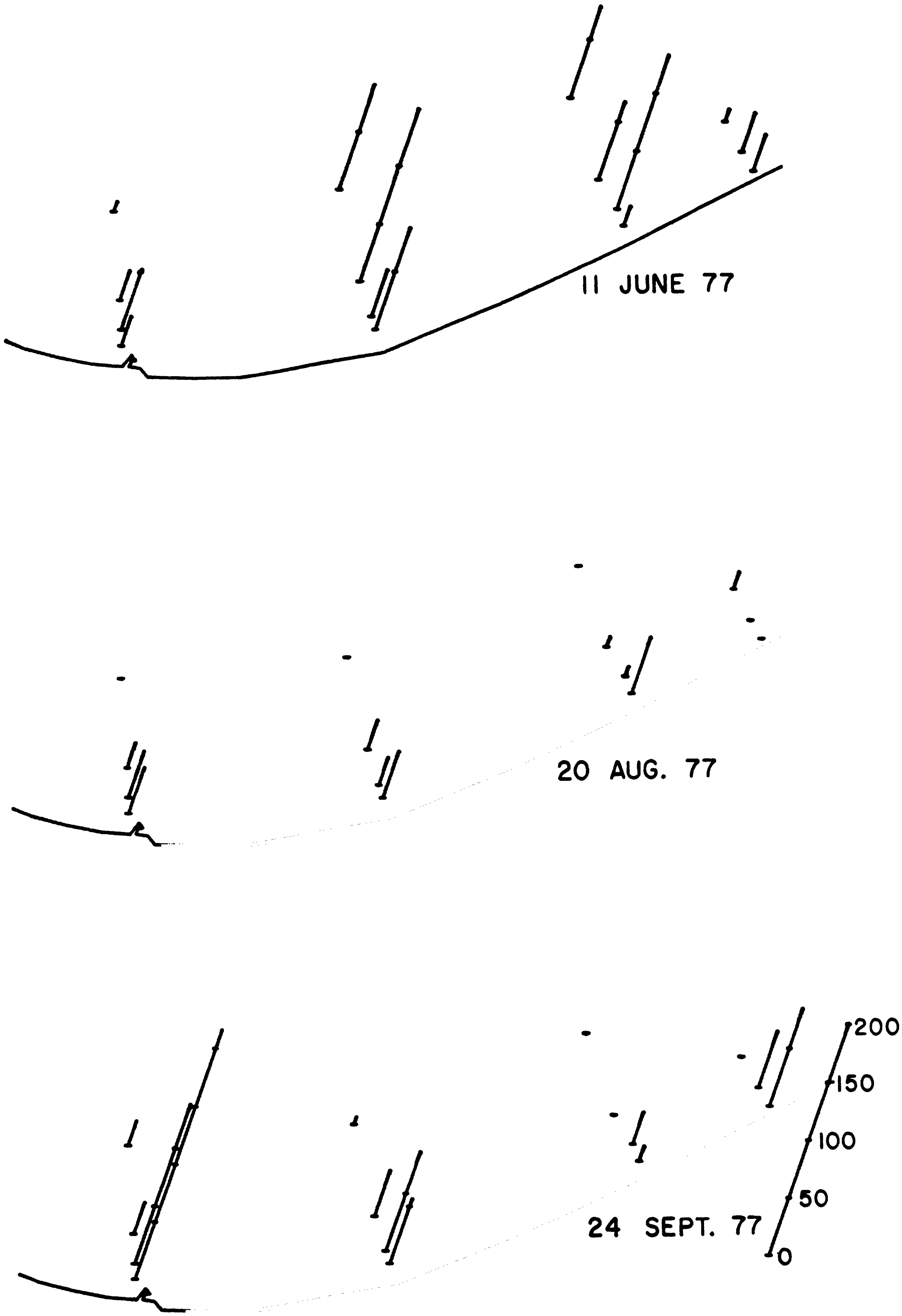

FIG. 14. Distribution of Tabellaria flocculosa var. linearis.

Chlorophyta

Chlamydomonas spp. (Fig. 15)

This green flagellate was a dominant in the system in August, and occurred only in minimal numbers in June and September. In August, it displayed highest densities at the three nearshore stations at Gary and Burns Harbor. This species correlated at the .01 level in August with NO_3 and NH_3. Stoermer *et al*. (1975) noted that *Chlamydomonas* spp. was abundant in some areas of Lake Ontario, and reached its maximum populations around July.

Scenedesmus spp. (Fig. 16)

The genus *Scenedesmus* was found in fairly high numbers, and was represented by a variety of different species. Most species of *Scenedesmus* reported from the Great Lakes prefer eutrophic waters. In southern Lake Michigan, it was found in approximately similar numbers over all three dates with no trends apparent within a given cruise. Further substantiating this lack of habitat preference is the fact that no significant correlations were found when compared to any physico-chemical parameters.

Cryptophyta

Cryptomonas ovata Ehr. (Fig. 17)

This species is very common in all regions of the Great Lakes. In this study, over all three cruises it exhibited affinites for both the nearshore waters and the Gary and Burns Harbor regions. It does not appear to exhibit any seasonal trends. In both August and September, it correlated highly (.05 level) with conductivity, NO_3, and NH_3.

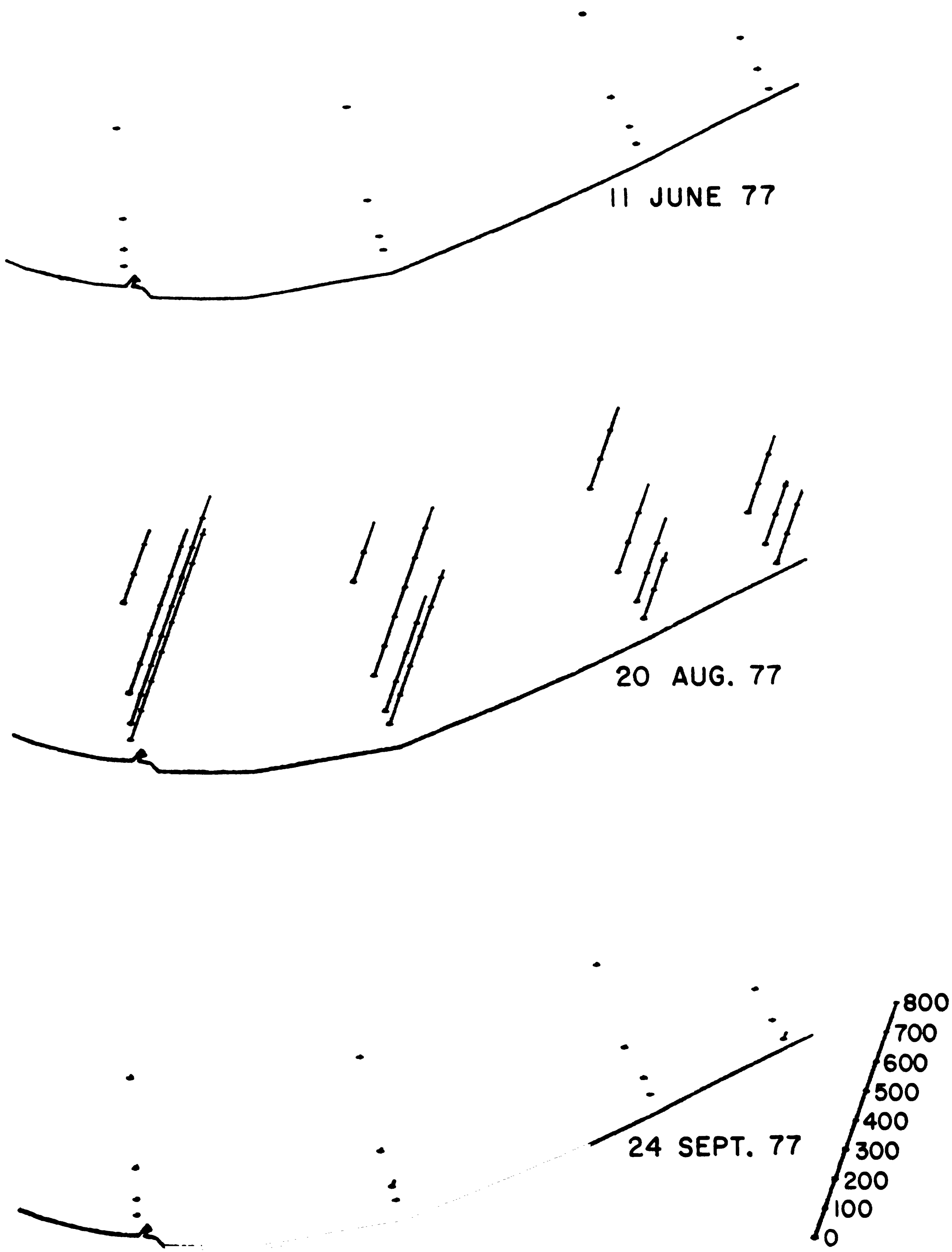

FIG. 15. Distribution of *Chlamydomonas* spp.

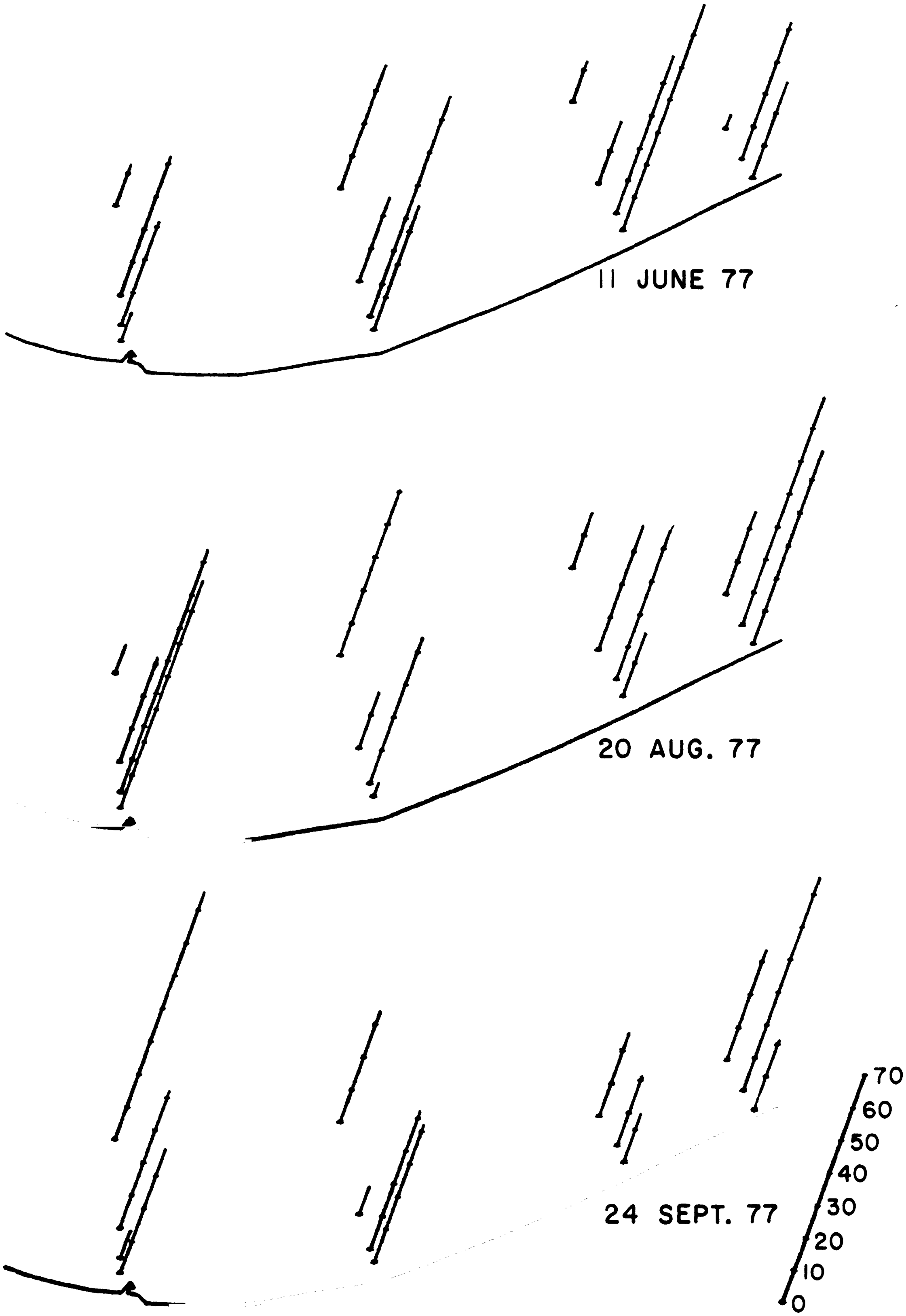

FIG. 16. Distribution of Scenedesmus spp.

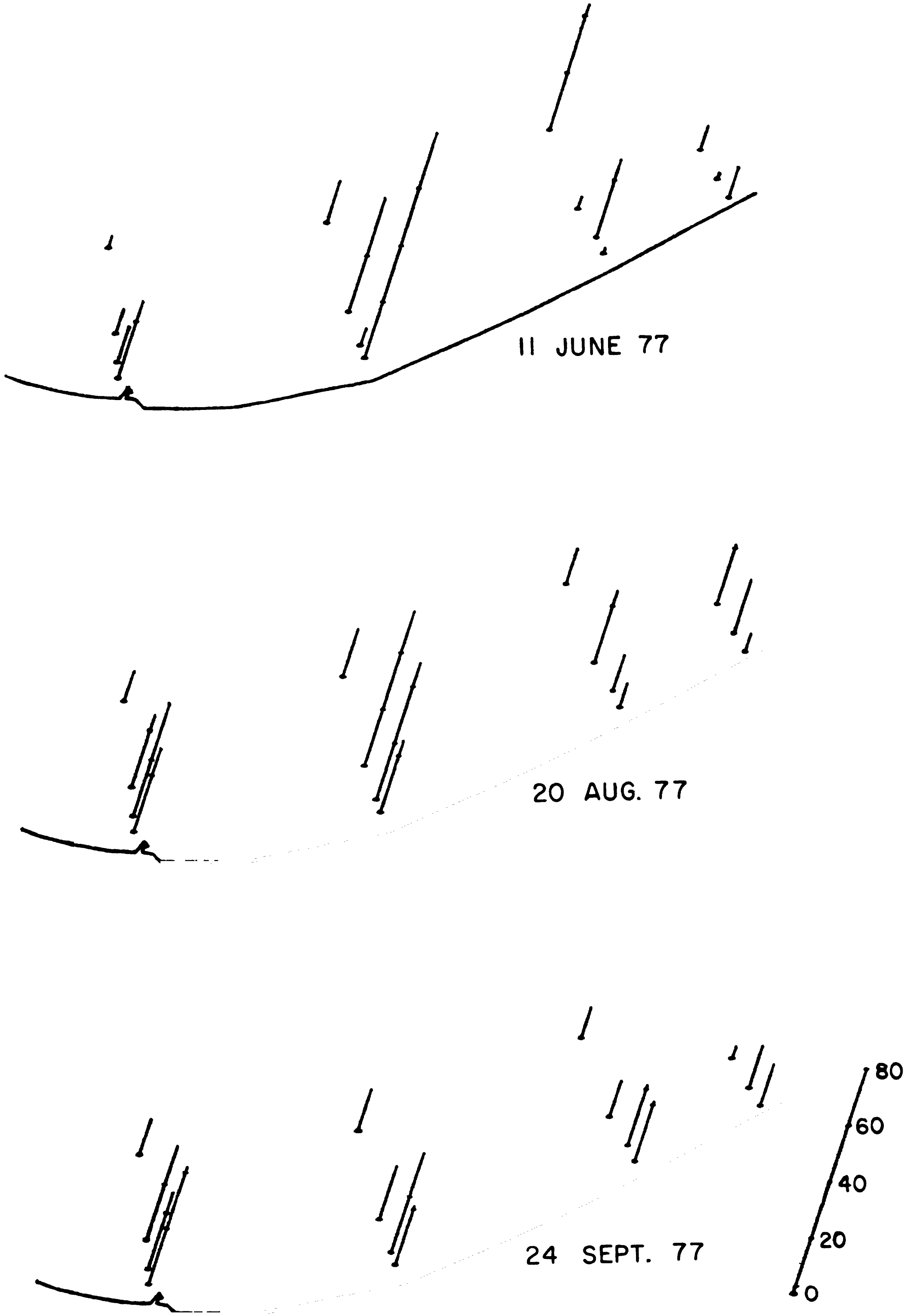

FIG. 17. Distribution of *Cryptomonas ovata*.

Cyanophyta

Anabaena flos-aquae (Lyngb.) Breb. (Fig. 18)

Low levels of this species are found consistently in the Great Lakes; however, high densities are found only in the more eutrophic regions within the system. Stoermer and Kopczynska (1967) found the maximum abundance of *A. flos-aquae* in southern Lake Michigan to be on the same order as in eastern Lake Ontario. In this study in June, it was found at only three of the stations sampled. By August, it was found scattered in about half of the stations, with a maximum occurrence at the nearshore station at Indiana Dunes. In September, it was found at 10 stations, with no trends apparent.

Anacystis incerta Dr. & Daily (Fig. 19)

This species is common in the summer and fall phytoplankton assemblages in the Great Lakes. Stoermer *et al*. (1975) noted that this species is most successful under conditions of silica depletion. In the June cruise, this species was not present to any significant extent. By August, it increased greatly, and was dominant at every station. It maintained these high numbers into September, and remained as one of the dominants. No trends could be detected within the sampling scheme, and this may be due to its pattern of indeterminate colonial growth, which causes varying degrees of error in abundance estimates.

Oscillatoria bornetii Zukal (Fig. 20)

This species has previously been reported from Lake Michigan mainly at the thermocline depth during summer stratification, but rarely in the surface

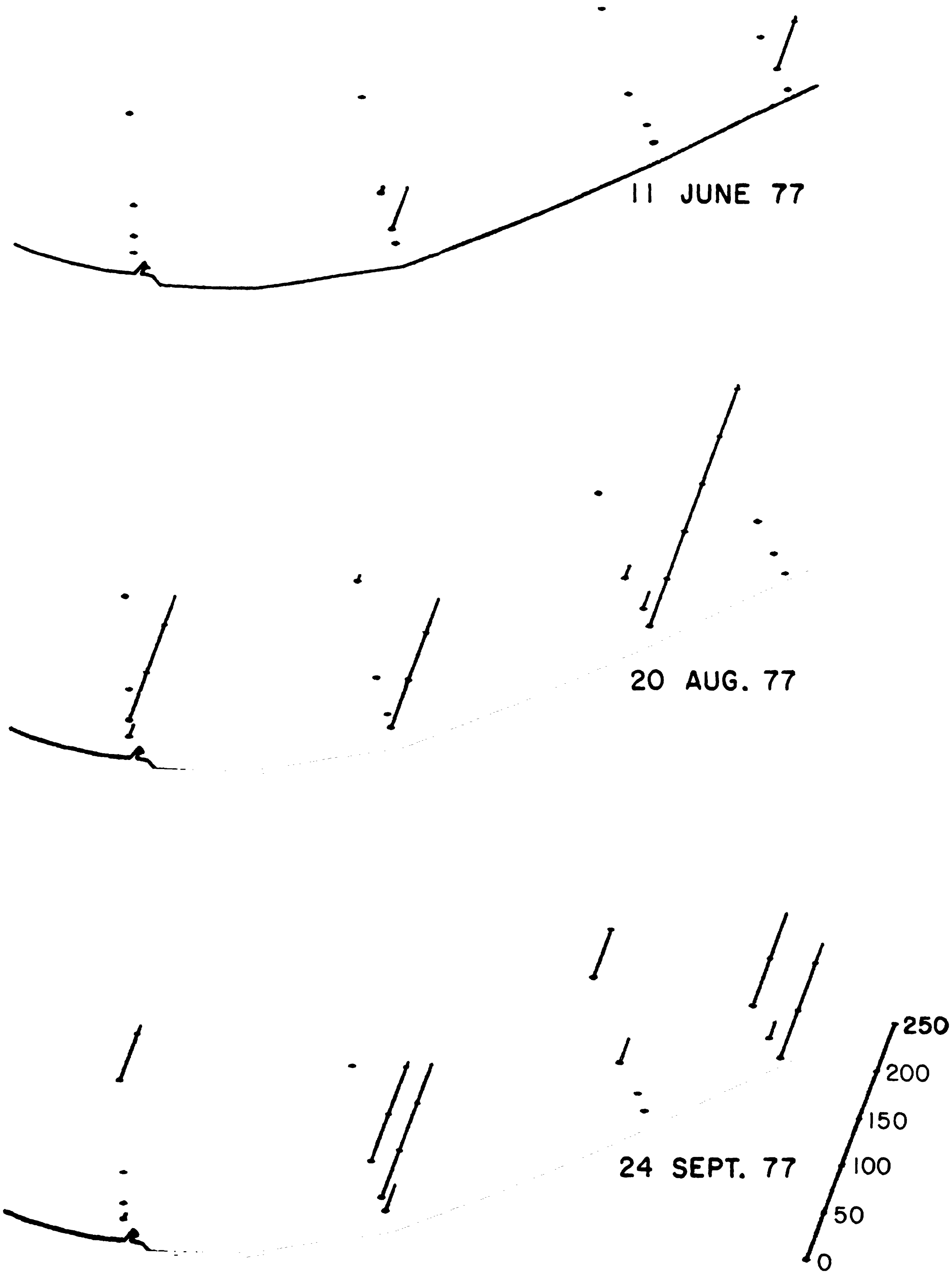

FIG. 18. Distribution of *Anabaena flos-aquae*.

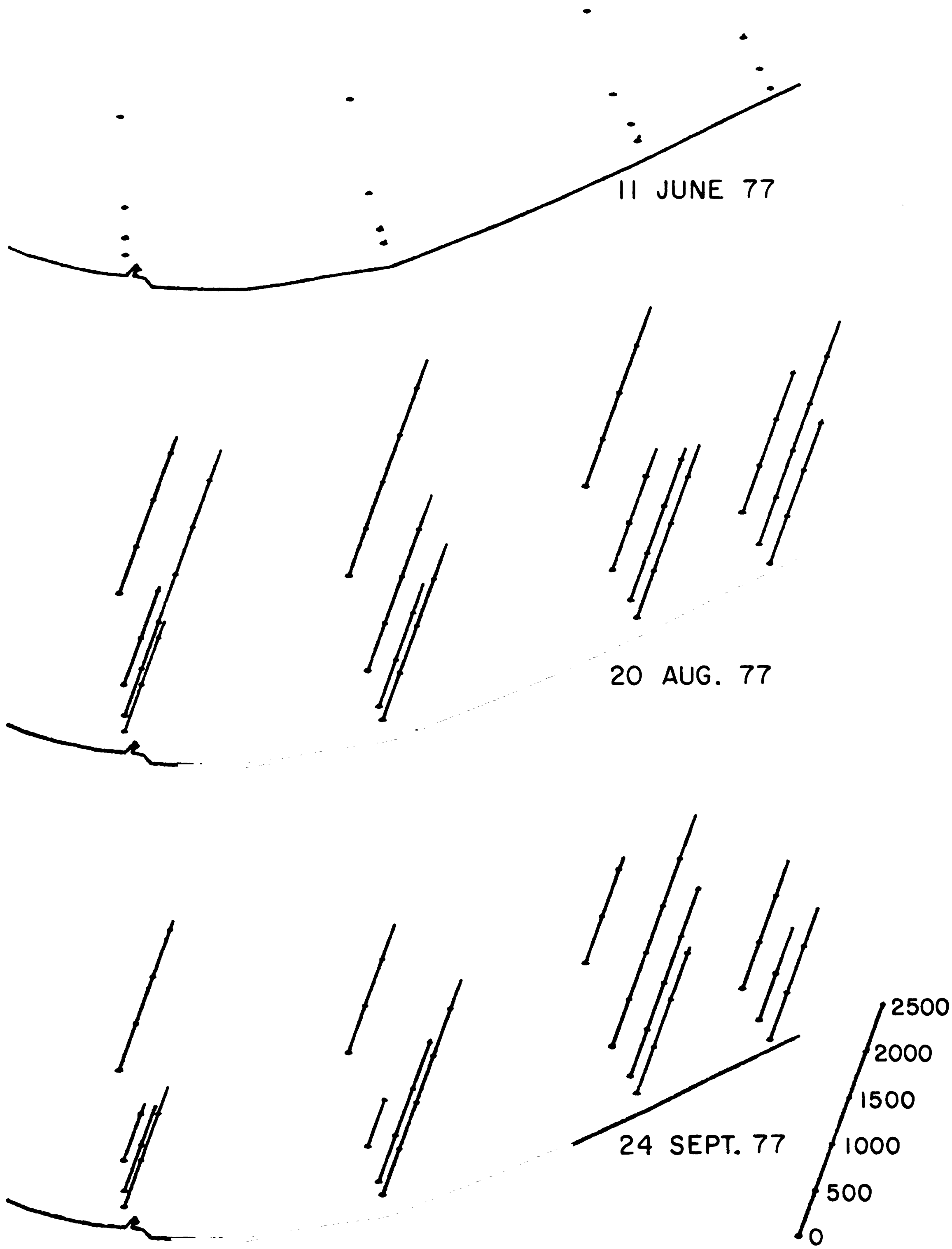

FIG. 19. Distribution of *Anacystis incerta*.

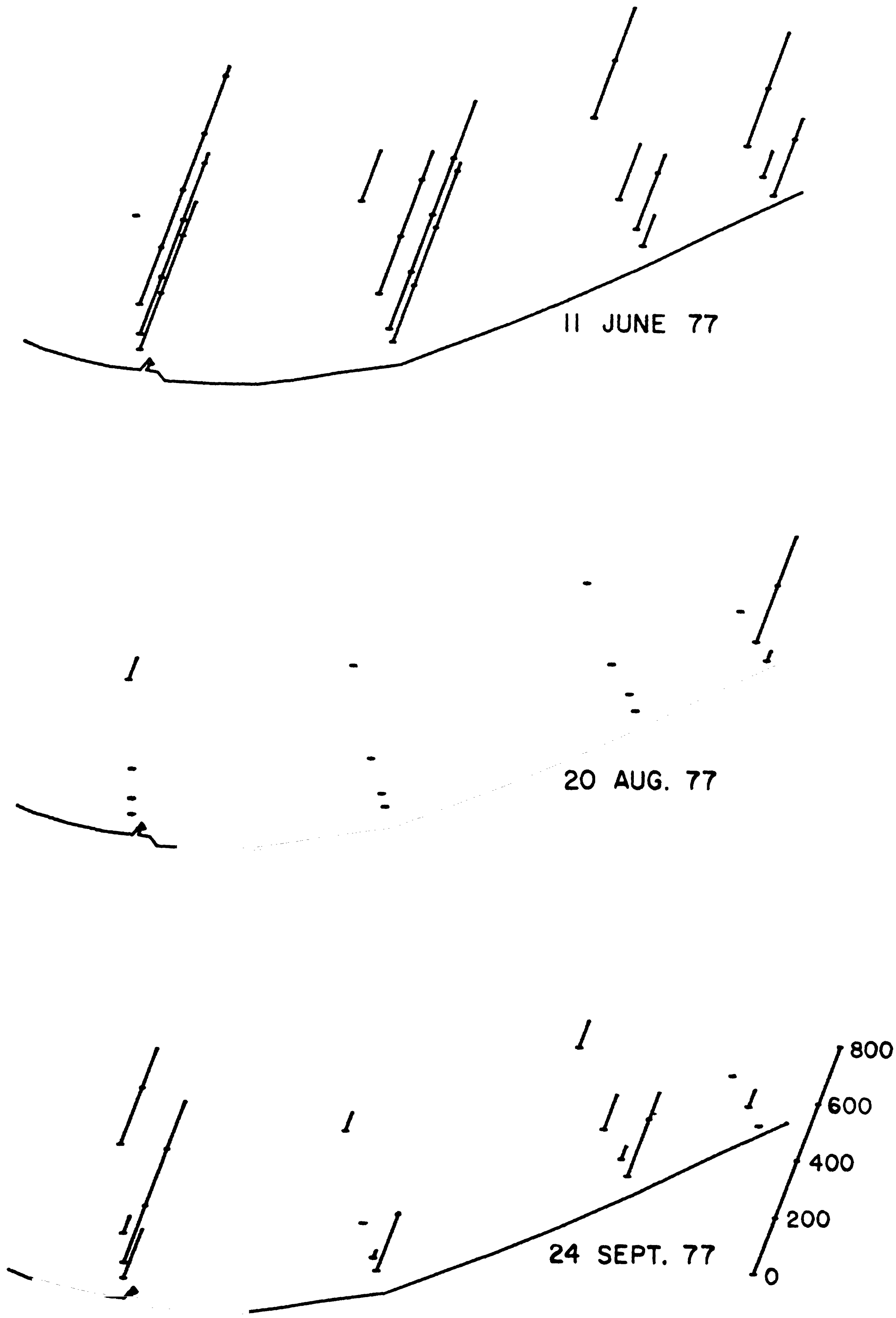

FIG. 20. Distribution of Oscillatoria bornetii.

waters. It has only occasionally been found in abundance in the upper Great Lakes. In southern Lake Michigan, in June, it was one of the dominants. It tended to be in higher densities both nearshore and at the Gary and Burns Harbor regions. In August, it decreased in numbers, and only the 1/2 mile station off Michigan City had an extensive population. It increased slightly in September, with highest abundances along the Gary Harbor transect.

Microflagellates

Haptophyte sp. #1 (Fig. 21)

One group of flagellates which may be playing an increasingly larger role, especially in the Lake Michigan phytoplankton assemblages, are the haptophytes. Little is known about the freshwater ecology of this primarily marine group. *Chrysochromulina parva* has been reported from both Lake Erie and Lake Ontario. Munawar and Munawar (1975) regard it as one of the most numerically abundant species in the St. Lawrence Great Lakes. In Lake Ontario, Stoermer *et al*. (1975) found *Chrysochromulina parva* to be abundant, with its largest populations occurring in June and July. In southern Lake Michigan, Haptophyte sp. #1 was a dominant component of the system in June. Lowest densities were recorded at the 1/4 mile stations at each transect, and it appeared as if some type of nearshore inhibition effect was occurring. Highest abundances were found along the Gary Harbor and Indiana Dunes transects. Numbers decreased in August, with abundances lowest at the offshore stations. Densities further decreased into September, where this species played only a minor role in the system.

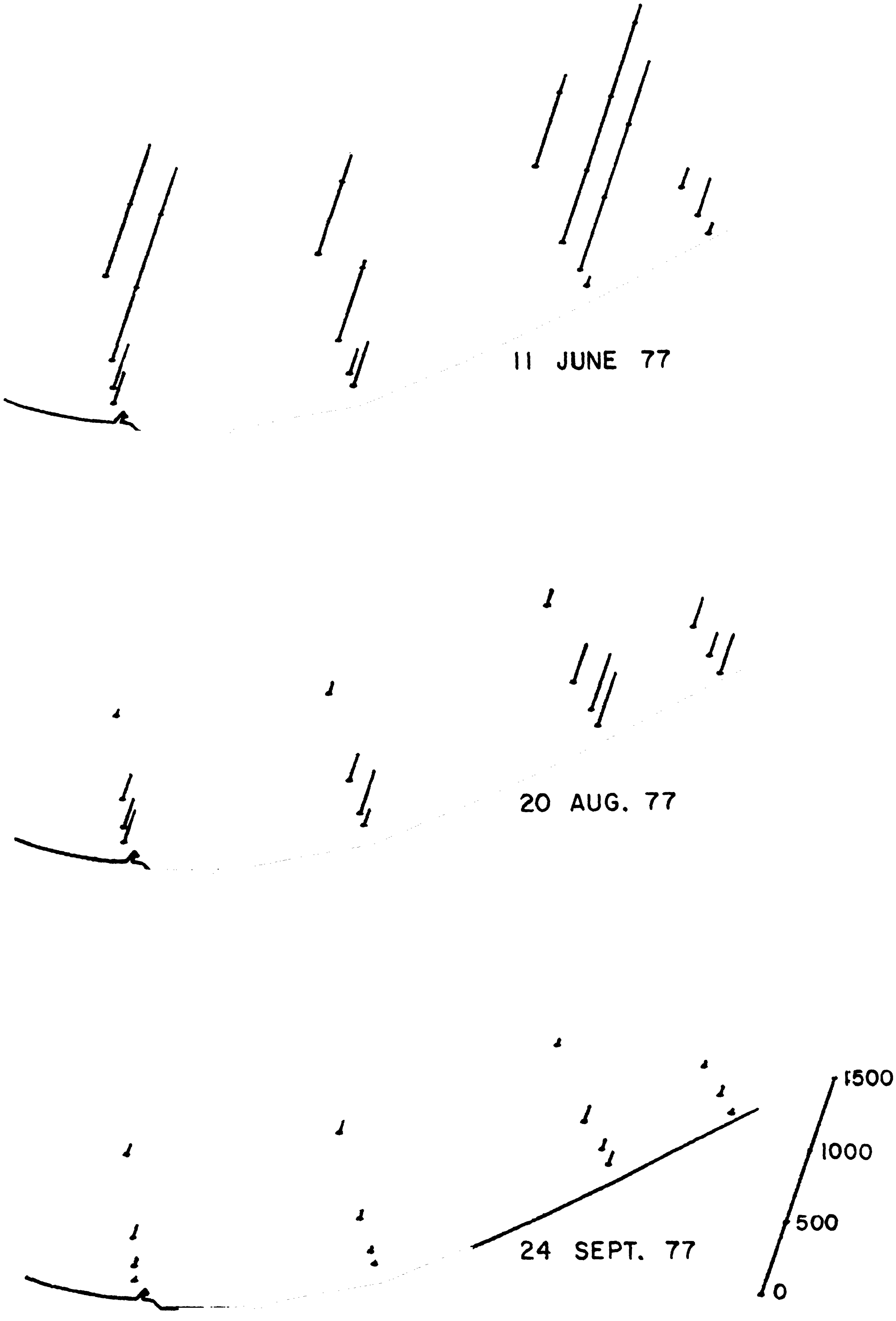

FIG. 21. Distribution of Haptophyte sp. #1.

DISCUSSION

There is no doubt that diatoms as a group have decreased in dominance in south Lake Michigan since the early 1960's, when Stoermer and Kopczynska (1967) found them dominant at all stations and all months. The diatoms that are now of consequence are typically those species associated with varying degrees of eutrophication. Green and blue-green algae are composing larger portions of the phytoplankton assemblages. They can outcompete diatoms, especially in the summer, under conditions of low silica and high temperatures. In this study, *Anacystis incerta* was the dominant taxon in both August and September. Additionally, phytoflagellates are now a major part of the Great Lakes system (Munawar and Munawar, 1975).

Within the past 50 years, chloride concentrations have been increasing in the Great Lakes. Beeton (1965) noted that chloride levels, along with other conservative elements, have been increasing in Lake Erie, Lake Ontario, and Lake Michigan since the early 1900's. A number of marine and halophilic algal species have been recorded in the Great Lakes, with most of these reported within the last twenty years. Stoermer (1978) noted that most of the phytoplankton species which have invaded the Great Lakes are halophilic in nature. In 1977, the brackish-water species *Biddulphia* sp. and *Terpsinoe musica* were recorded from southern Lake Michigan for the first time (Wujek, pers. comm.). In this study, a variety of salt tolerant forms were present in fairly high numbers, including *Cyclotella cryptica, Cyclotella pseudostelligera, Diatoma tenue* var. *elongatum,* and *Synedra filiformis*. Also, two species of *Skeletonema*, a brackish-water genus, were found. Haptophytes were found as a dominant in June, and this group appears to be increasing in

abundance in the Great Lakes.

Aside from the halophilic forms, other species typical of eutrophic waters were present. Many of the diatoms found in abundance were species described by Stoermer and Yang (1969) as tolerating moderately disturbed portions of the Great Lakes. Included in this group are Asterionella formosa, Fragilaria crotonensis, Stephanodiscus alpinus, Stephanodiscus minutus, and Synedra ostenfeldii. Other species found in southern Lake Michigan that are common in disturbed areas include Nitzschia spp., Stephanodiscus hantzschii and Stephanodiscus subtilis. In the green algae, the genus Scenedesmus is common in eutrophied areas. It was also noted that, in many instances, those species which were found to tolerate disturbed waters were found in higher densities at the Gary Harbor and Burns Harbor regions than at the eastern-most two transects.

One of the more striking aspects of phytoplankton distribution in the area of study is the atypically large abundance of species of the genus Nitzschia, particularly species such as N. palea and other forms which are often found in areas with extremely degraded water quality conditions. Cholnoky (1968) and others have noted that many members of this genus are often associated with high levels of organic or reduced nitrogen compounds. Species such as N. palea are, in fact, often considered to be indicative of this type of pollution. Although NH_4 levels are not extremely elevated at the stations studied, our data suggest that this type of perturbation may be an important factor in the area of study. This hypothesis is further enhanced by the fact that the occurrence of Nitzschia species reported to be tolerant of organic loadings is positively correlated with estimates of aerobic heterotroph abundance developed and furnished to us by the EPA Region V laboratories.

In the August cruise, with low silicon levels and increased temperatures,

diatoms were found in low densities. Only *Cyclotella comensis* and *Cyclotella stelligera* were able to thrive under these conditions to any significant extent. Both of these species have been reported to be extremely tolerant of low silica levels, and it appears they can outcompete other species when such conditions exist. It is interesting to note that in August, *C. comensis* was found in higher numbers along the more polluted Gary and Burns transects, while *C. stelligera* was recorded in greater abundances at the less disturbed eastern-most two transects.

The sudden dominance of *Cyclotella comensis*, a diatom which, so far as we have been able to ascertain, was exceedingly rare in Lake Michigan prior to 1975 is difficult to interpret. This species has become an important element of the flora throughout the lake (GLRD, unpublished data) during the summer and fall. Similar blooms have been noted in Lake Huron (Lowe, 1974; Stoermer and Kreis, in press). Although the ecological tolerance of this species is very poorly known, it is usually reported from oligotrophic systems which are under some nutrient stress. Based on data from Lake Huron, the species is very tolerant of low levels of dissolved silica but does not tolerate nitrate depletion (Stoermer and Kreis, in press). In Lake Huron it forms large late summer and fall blooms in the interface waters of Saginaw Bay and Thunder Bay. It is interesting to note that *C. comensis* has apparently effectively replaced *C. michiganiana*, an indigenous species which was previously a consistent summer dominant in Lake Michigan. Although there may be several plausible explanations for this, it would appear that the superior competetive ability of *C. comensis* may be related to its tolerance of low silica levels, and thus related to continued phosphorus stress on the system.

It should be recognized that, due to the timing of collections in the

present study, maximum levels of phytoplankton standing crop were probably not encountered. Previous studies have shown that maximum phytoplankton density and maximum regional differentiation of the flora occur during the spring thermal bar period. In most instances, phytoplankton abundance in the nearshore zone, except in the immediate vicinity of strong sources, is on average lower, but extremely variable following stratification. The samples reported here thus represent a "best case" situation so far as illustrating the effects of eutrophication and salinification on the phytoplankton flora is concerned. It would be reasonable to expect much larger and better defined trends within the area of study during the spring thermal bar period when the dispersion of inputs tends to be constrained by the thermal bar.

Another interesting result of the study is the documentation of the increasing importance of microflagellates in the Lake Michigan phytoplankton. In the Great Lakes system, extreme abundance of these organisms is generally associated with regions which have undergone extensive modification. Unfortunately the taxonomy of microflagellates in the Great Lakes is very poorly known since many of them can be identified with certainty only with the aid of the electron microscope. Because of their increasing ecological importance more research should be devoted to determining what entities are present and to developing techniques whereby reliable population estimates can be made.

One of the characteristics which appears to distinguish the phytoplankton flora of the study area from that of previously studied nearshore localities is the abundance of filamentous blue-green algae. Although the Cyanophyta have become more abundant in the offshore waters of Lake Michigan in the past decade, the most numerically important forms are generally coccoid species.

Although these forms are also a dominant element of the phytoplankton flora in the study area, filamentous species are relatively more abundant than expected.

Running concurrently with this study was an investigation into the phytoplankton assemblages of Green Bay (Stoermer and Stevenson, in press). The phytoplankton components of both systems are highly comparable. The dominant taxa of Green Bay for May, August, and October 1977 included *Anacystis incerta*, *Cyclotella comensis*, *Gloeocystis planctonica*, and *Rhodomonas minuta*. These species were also of major importance in southern Lake Michigan in 1977. Total densities were higher in Green Bay, averaging 5400 cells/ml, while southern Lake Michigan averaged only 4400 cells/ml.

The August sampling period in Green Bay was also dominated by the Cyanophyte *Anacystis incerta*, with *Cyclotella comensis* the dominant diatom. *Cyclotella stelligera* was not present in appreciable numbers in Green Bay, possibly due to the more perturbed conditions found there than at the eastern-most two transects of southern Lake Michigan where it was found in fairly high abundances. Phytoflagellates were also of importance in Green Bay in August.

In October in Green Bay, similar to the September sampling period in this study, *Anacystis incerta* was still the dominant species at a majority of stations with diatoms and phytoflagellates secondarily important. It is interesting to note that, for all of the sampling dates, the flagellate composition was very similar. Species of consequence common to both systems include: *Chroomonas* spp., *Cryptomonas marssonii*, *Cryptomonas ovata*, *Ochromonas* spp., *Ochromonas vallesiaca*, *Rhodomonas minuta*, and undetermined haptophytes.

In 1971 and 1972, GLRD collected and analyzed samples along the Burns Harbor transect. This allowed for the comparison of the phytoplankton

assemblages on a temporal scale. In June 1971, at the 1/4 mile station, a plume emerging from Burns Ditch was intersected and a bloom condition of 31,000 cells/ml was recorded. Diatoms, most of which were centrics, composed 98% of the assemblage. The plume did not reach the three stations further offshore, and total numbers averaged only 2500 cells/ml, with Rhizosolenia gracilis the dominant taxon. Diatoms as a group were also dominant, averaging 70% of the phytoplankton component. In June 1972, diatoms were once again most numerous, averaging 93% of the assemblage. The major taxa included Stephanodiscus tenuis and S. minutus. In June 1977, the assemblage was different than five and six years previous. The blue-green algal filament Oscillatoria bornetii and undetermined haptophyte species were most numerous. Diatoms as a group were still dominant, but only composed 38% of the assemblage. Blue-green algae increased to 23% of the phytoplankton component, whereas in 1971 and 1972 they averaged only about 2.5%. Phytoflagellates as a group increased dramatically in importance, averaging 31% of the assemblage in June 1977, while in 1971 and 1972 they averaged only 4.2 and 1.5% respectively.

The August phytoplankton assemblage in 1977 appeared to have changed from the earlier studies. In 1977, the blue-green algae, mainly due to Anacystis incerta, were dominant, while diatoms as a group were most abundant in 1971 and 1972. In 1971 and 1972, blue-green algae averaged about 23% (300 cells/ml) of the assemblage, while in 1977 they averaged about 52% (2030 cells/ml) off Burns Harbor. However, the blue-green algal species present over the three years were similar, mainly belonging to the genera Anacystis and Gomphosphaeria. As in June, flagellates were found in much higher abundances in 1977 than in the previous years. In 1971 and 1972 they averaged 7% (180 cells/ml) and 1% (14 cells/ml) respectively, and increased to 22% (890 cells/ml) of the assemblage

in 1977.

In September, blue-green algae were dominant over all three years, averaging 66% (1200 cells/ml), 61% (3500 cells/ml), and 49% (1660 cells/ml) for 1971, 1972, and 1977 respectively. Interestingly, *Anacystis incerta* was the dominant taxon for all three years. Diatoms composed a larger portion of the assemblage in 1977 due to the appearance of *Cyclotella comensis*, a species not found in the earlier two years. Once again, flagellates were found in greater abundances in 1977 (14%), than in 1971 (1%) or 1972 (3%).

From the analysis of the phytoplankton component over the three years, some definite assemblage shifts can be noted. These include:

1. An increase in filamentous blue-green algae in 1977;

2. An earlier seasonal dominance of blue-green algae in 1977, to the point that they are found in higher abundances in June, and are dominant in August;

3. Extremely large increases in the flagellate component;

4. A decrease in the relative abundance of the diatom component in May and June, with it now being dominated by *Cyclotella comensis* and *C. stelligera* in the summer months under silica-limited conditions.

It still appears that the cultural eutrophication of southern Lake Michigan is continuing, albeit at a slower rate than five to ten years ago. Under silica-depleted summer conditions, blue-green algae, phytoflagellates, and low-silica-tolerant diatoms are now the dominant phytoplankters in the system. However, those diatom species characterized by Stoermer and Yang (1969) as thriving only in disturbed habitats are not present in large abundances in 1977 in southern Lake Michigan, although it is possible that they may have been present in April and May under thermal bar conditions.

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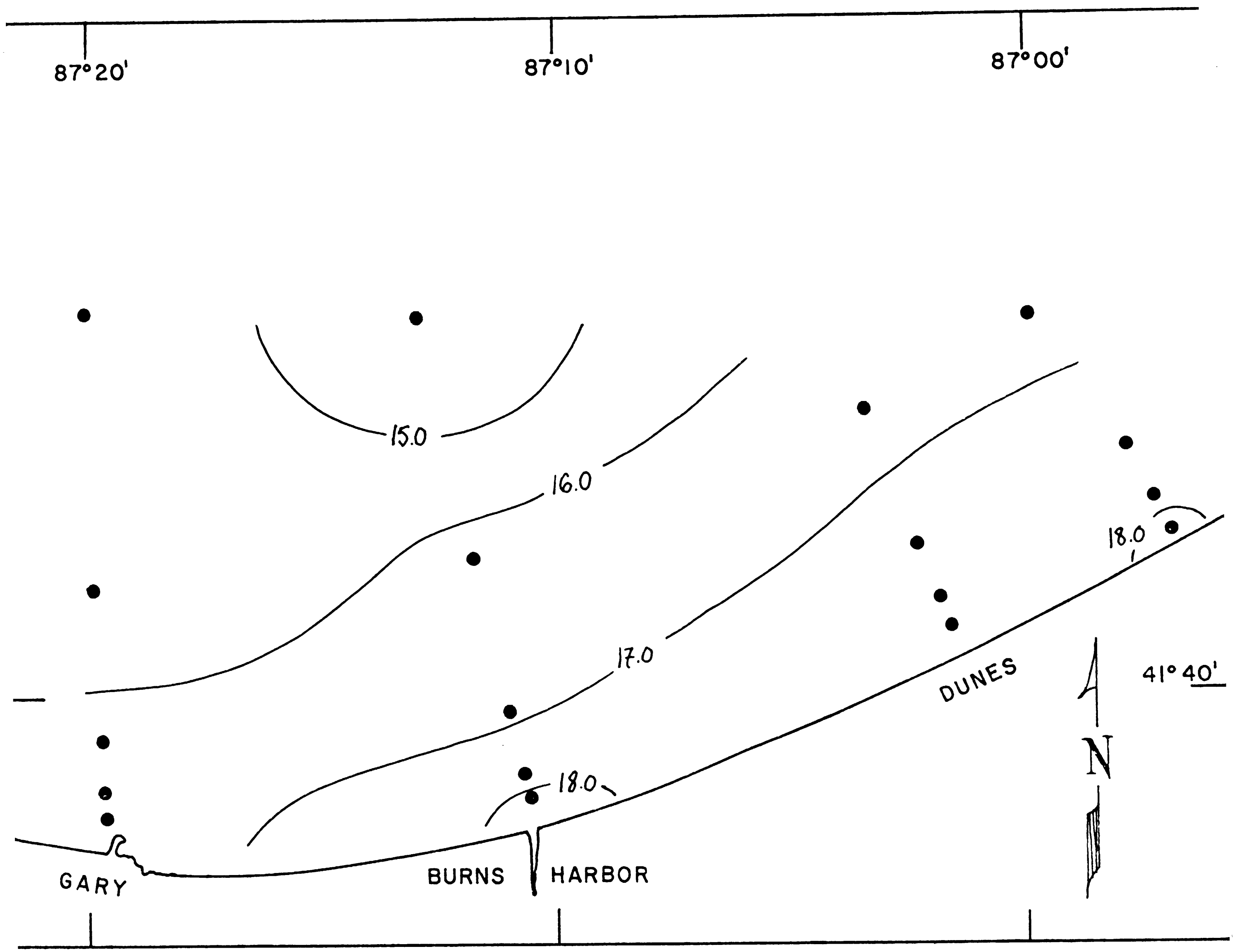
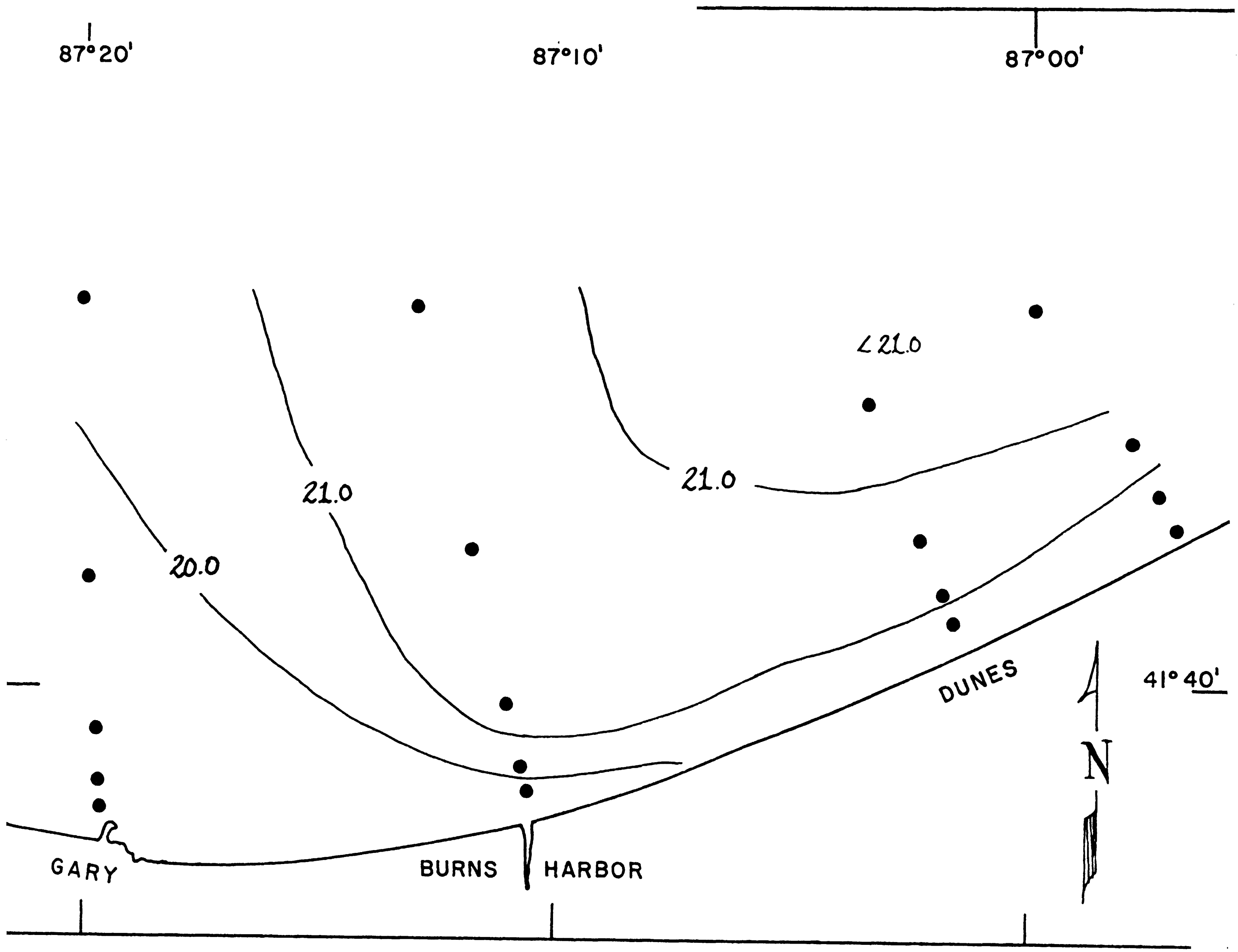
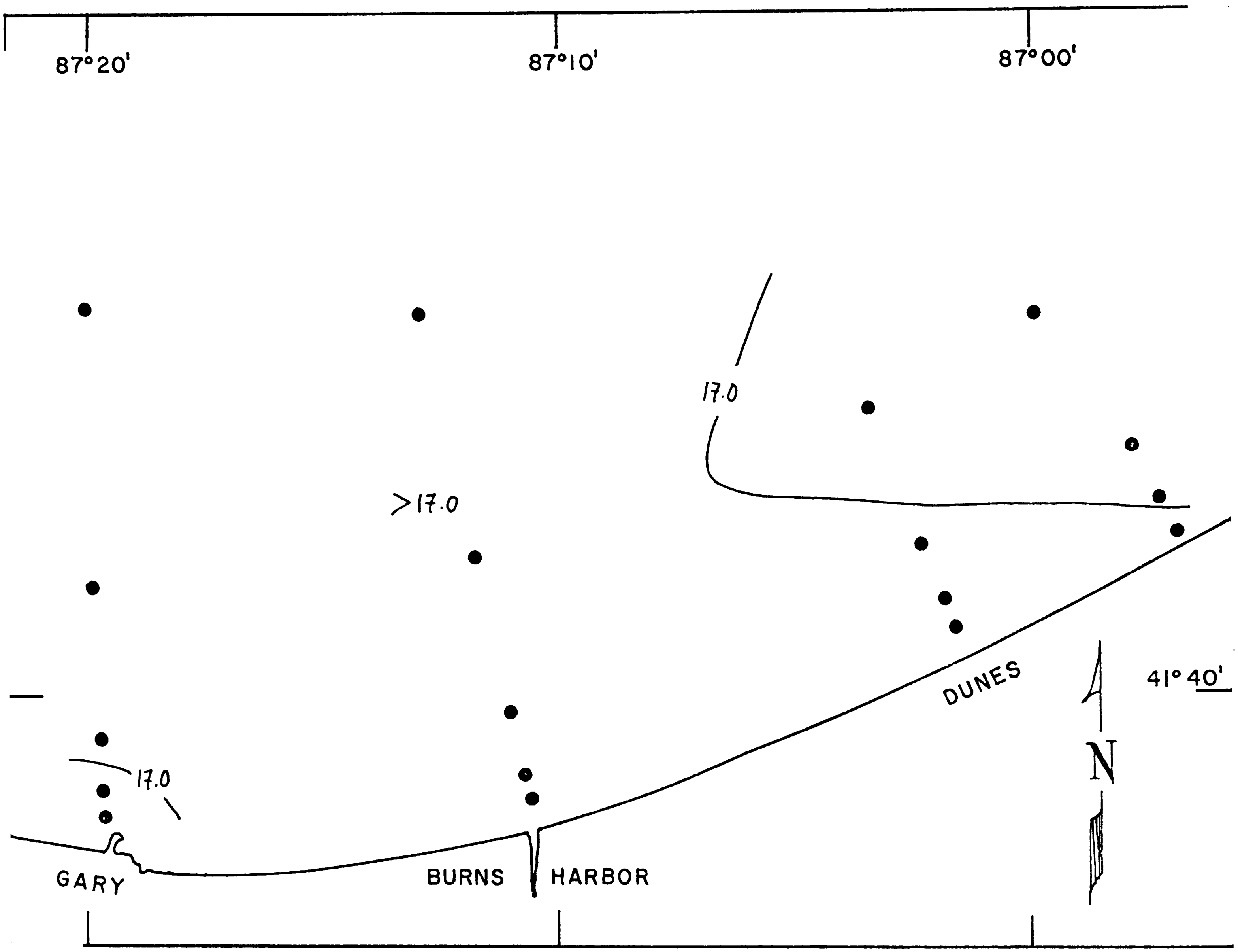


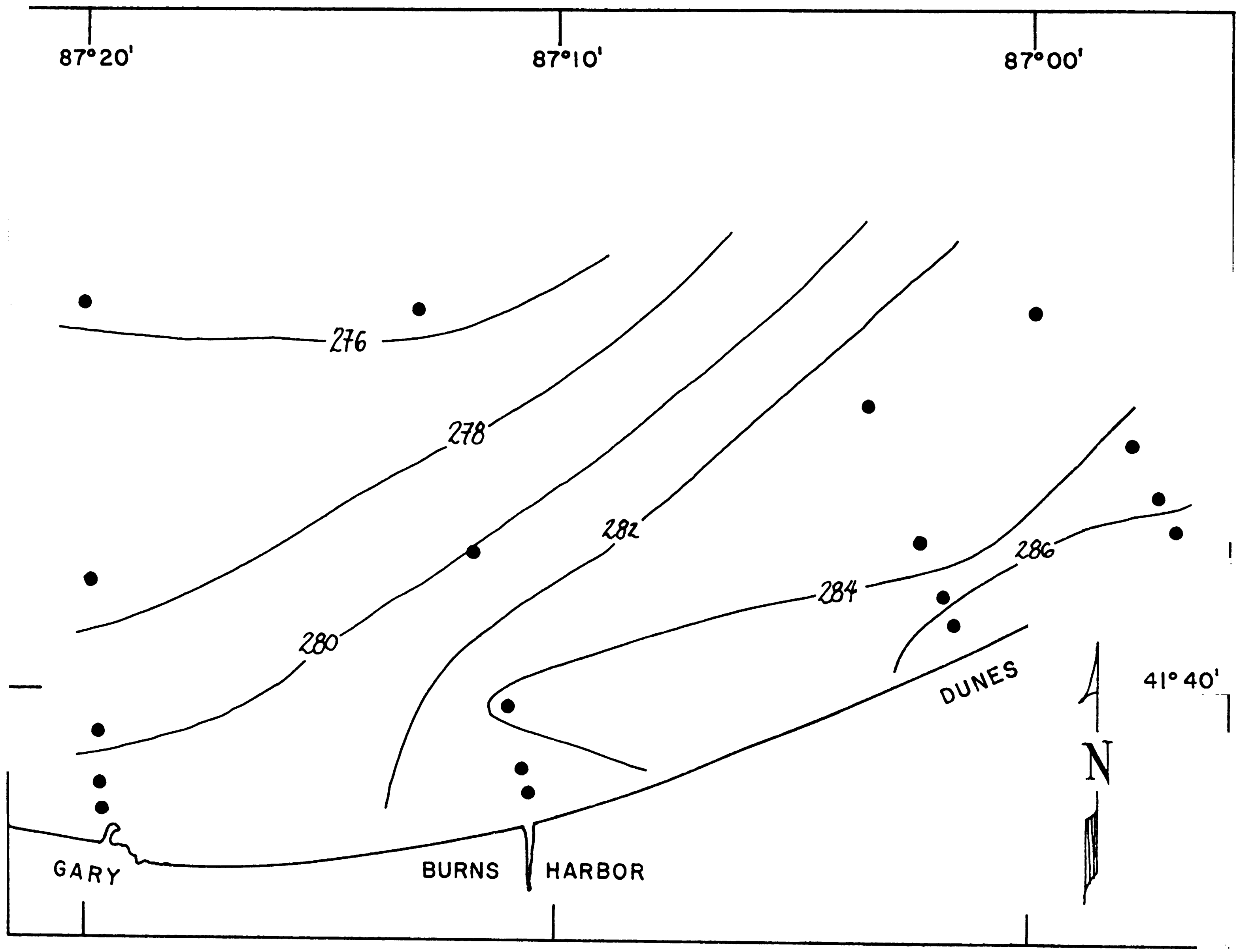
Appendix Figure 1. Temperature contours, southern Lake Michigan; 11 June, 1977.



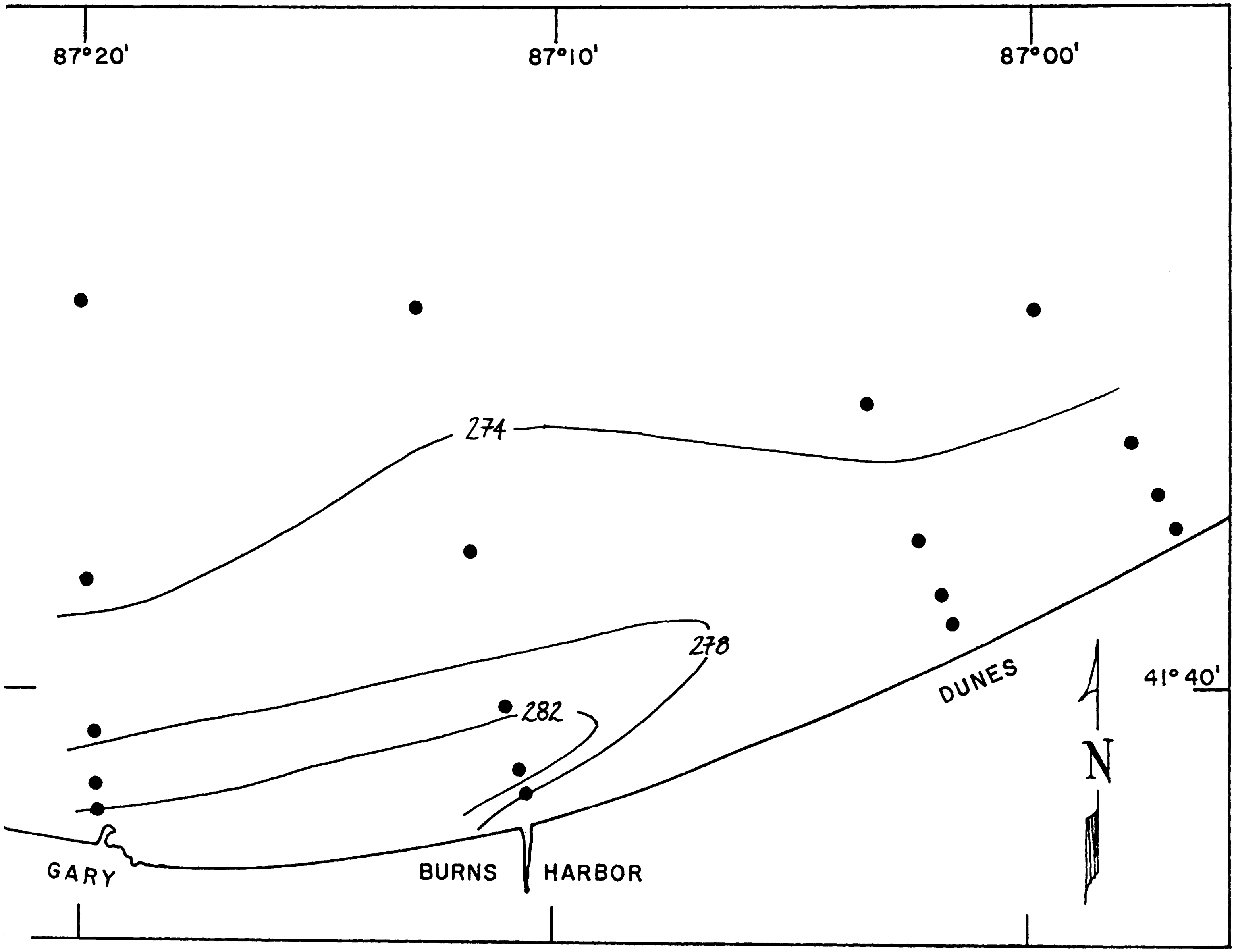
Appendix Figure 2. Temperature contours, southern Lake Michigan; 20 August, 1977.



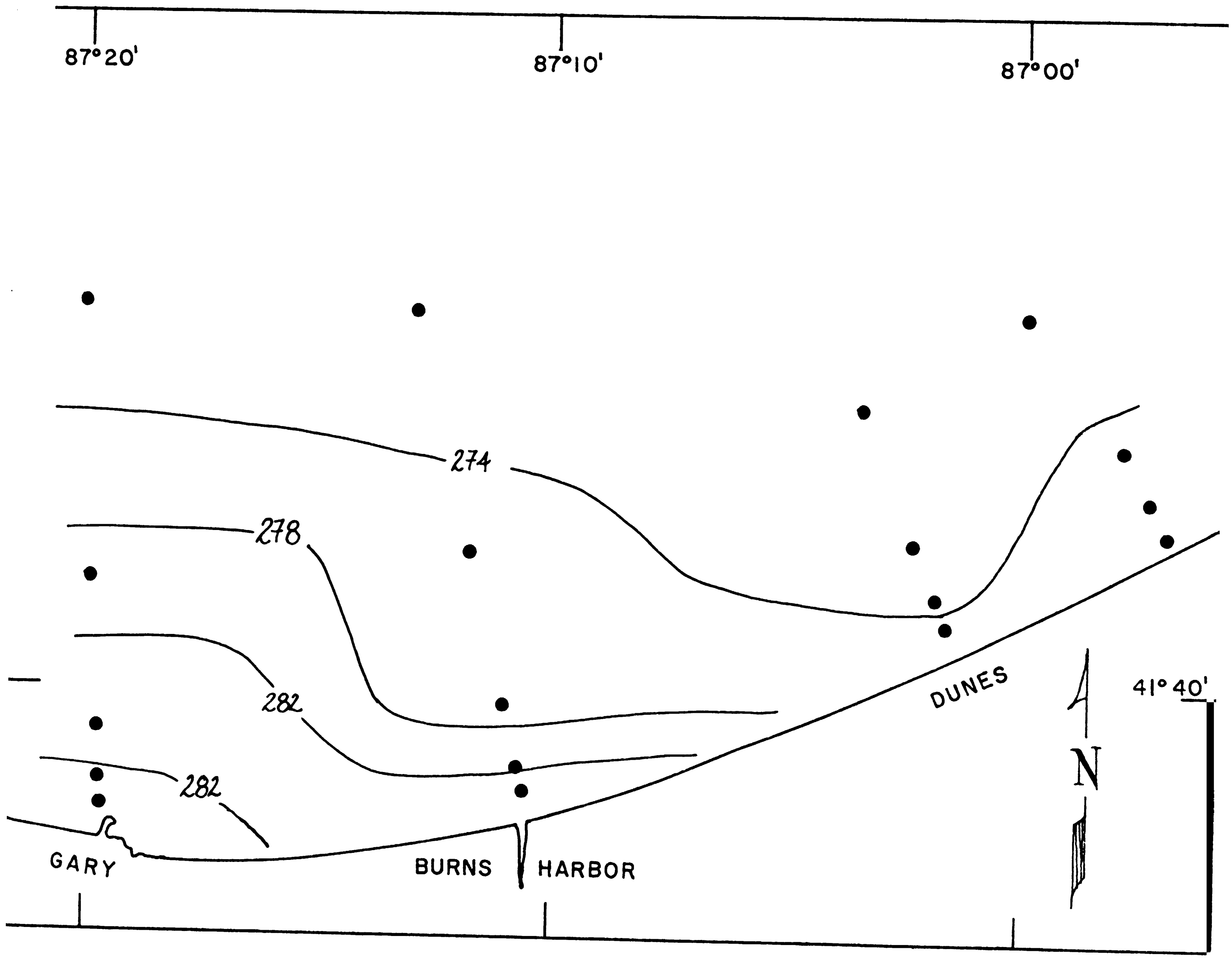
Appendix Figure 3. Temperature contours, southern Lake Michigan; 24 September, 1977.



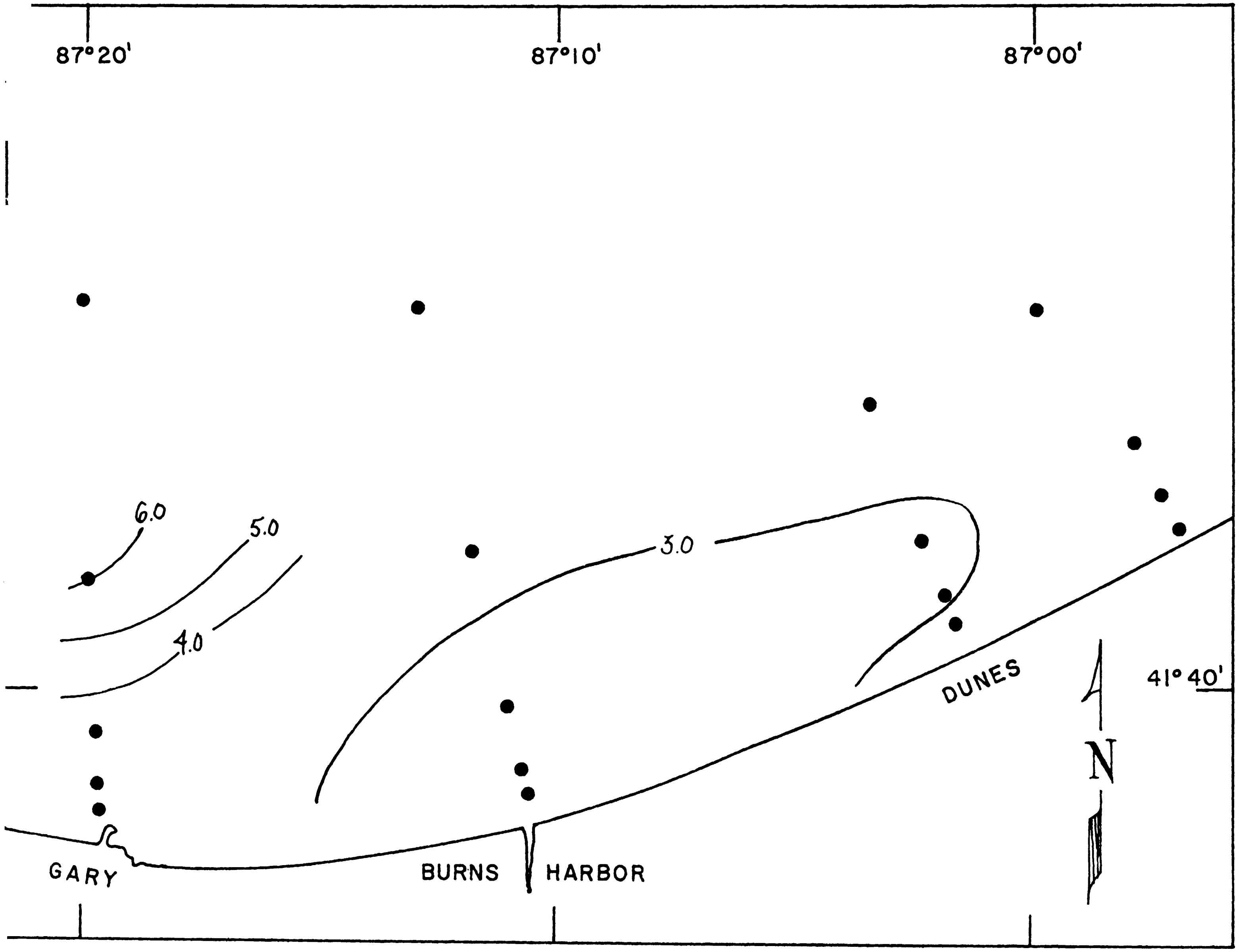
Appendix Figure 4. Conductivity contours, southern Lake Michigan; 11 June, 1977.



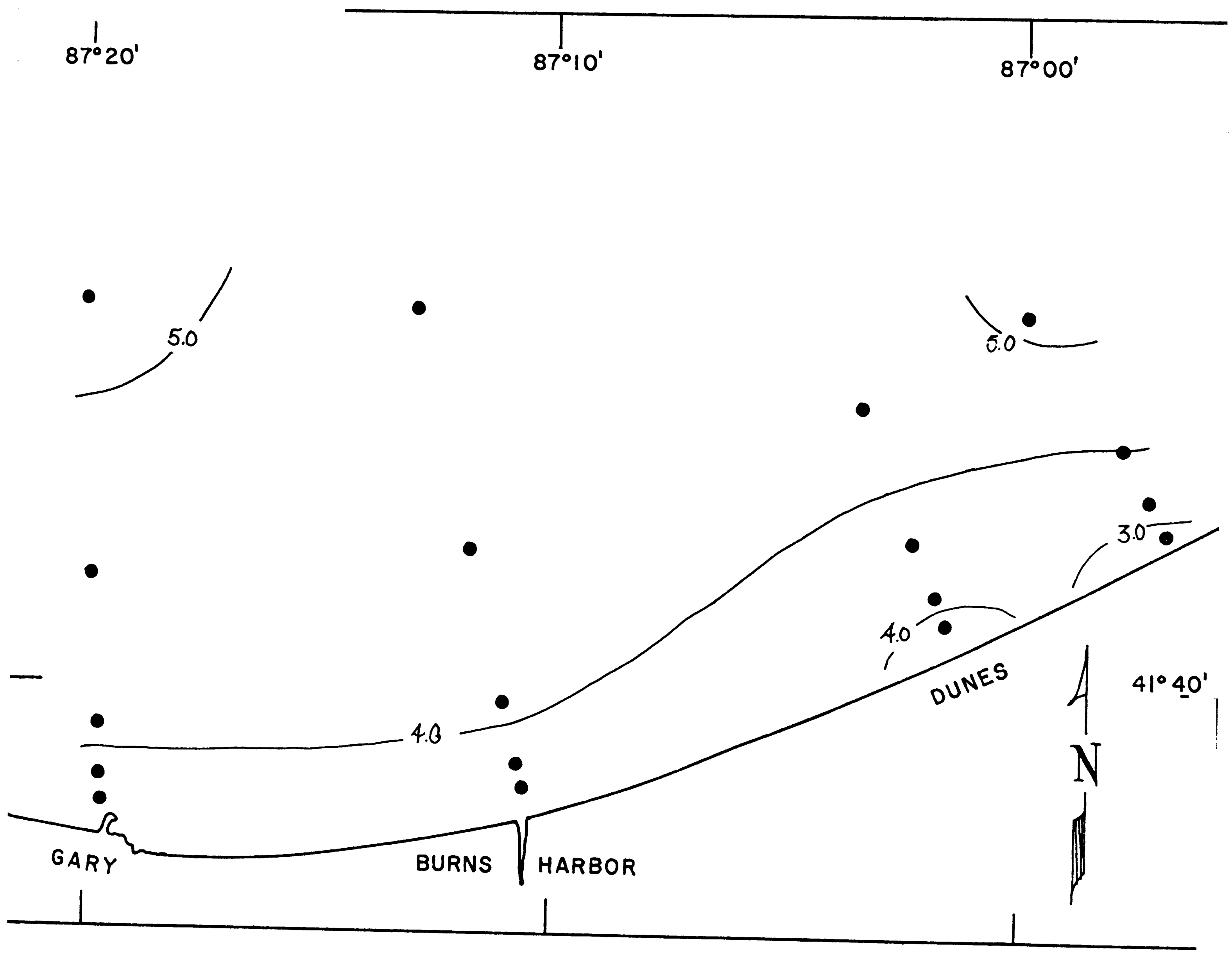
Appendix Figure 5. Conductivity contours, southern Lake Michigan; 20 August, 1977.



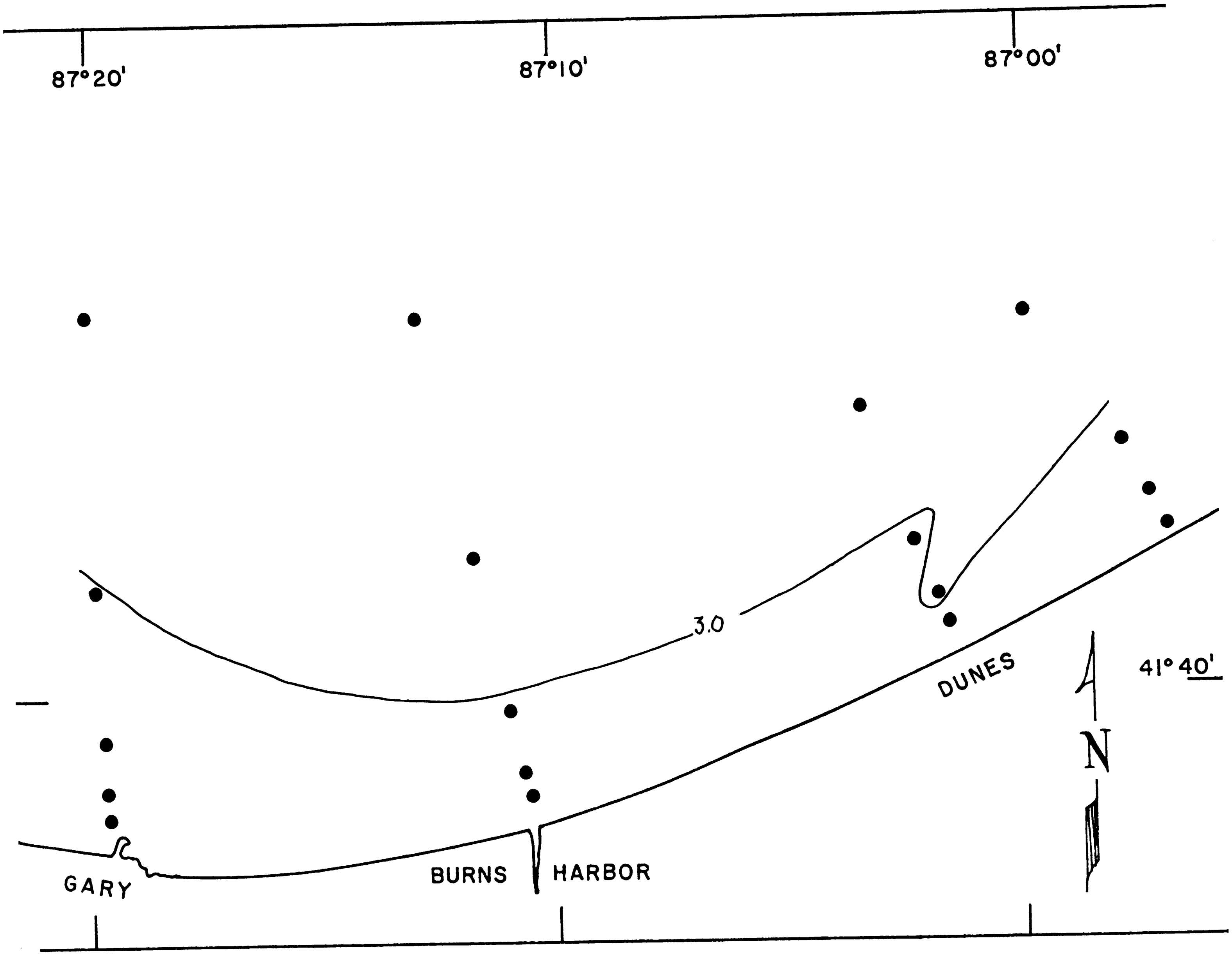
Appendix Figure 6. Conductivity contours, southern Lake Michigan; 24 September, 1977.



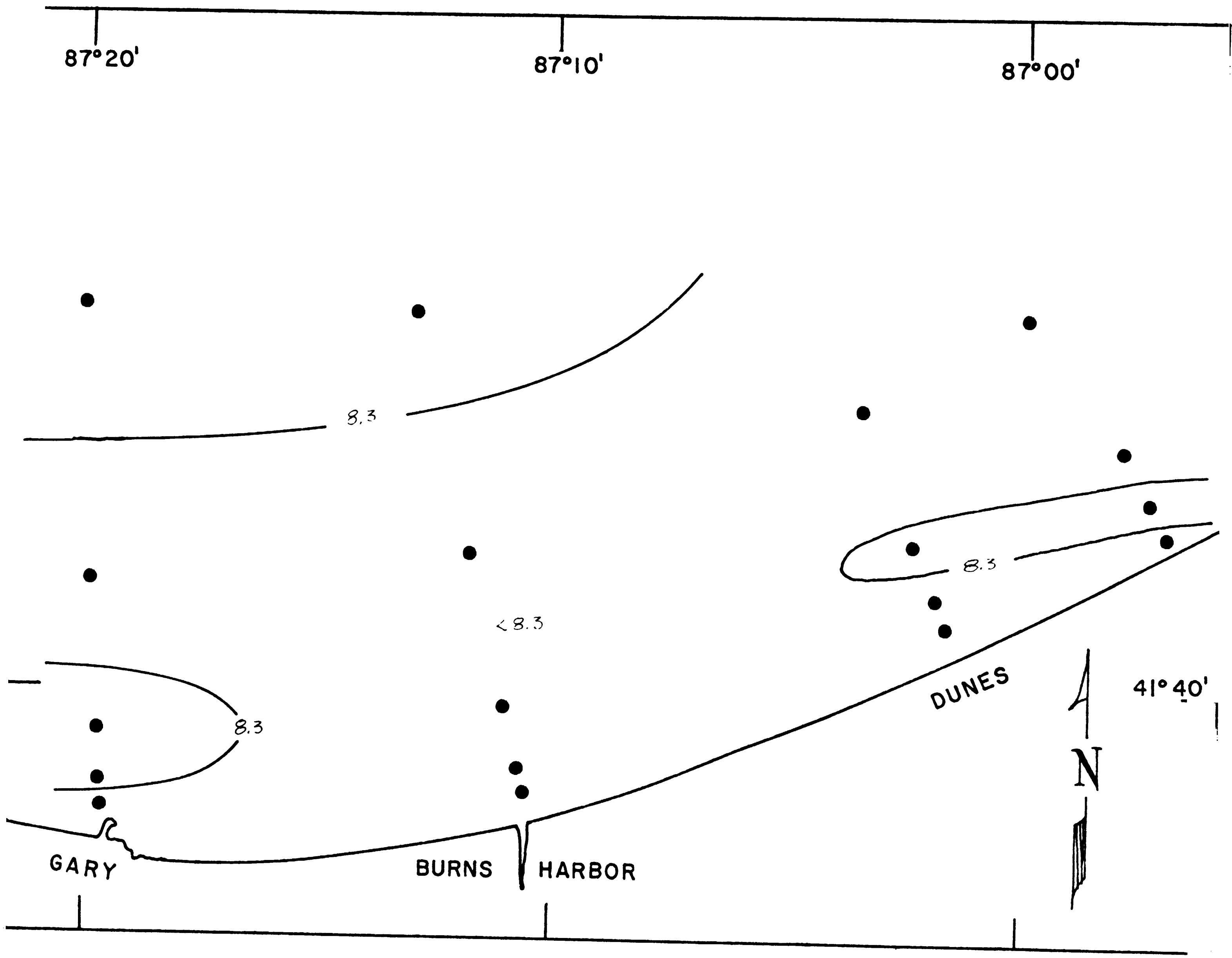
Appendix Figure 7. Secchi disc contours, southern Lake Michigan; 11 June, 1977.



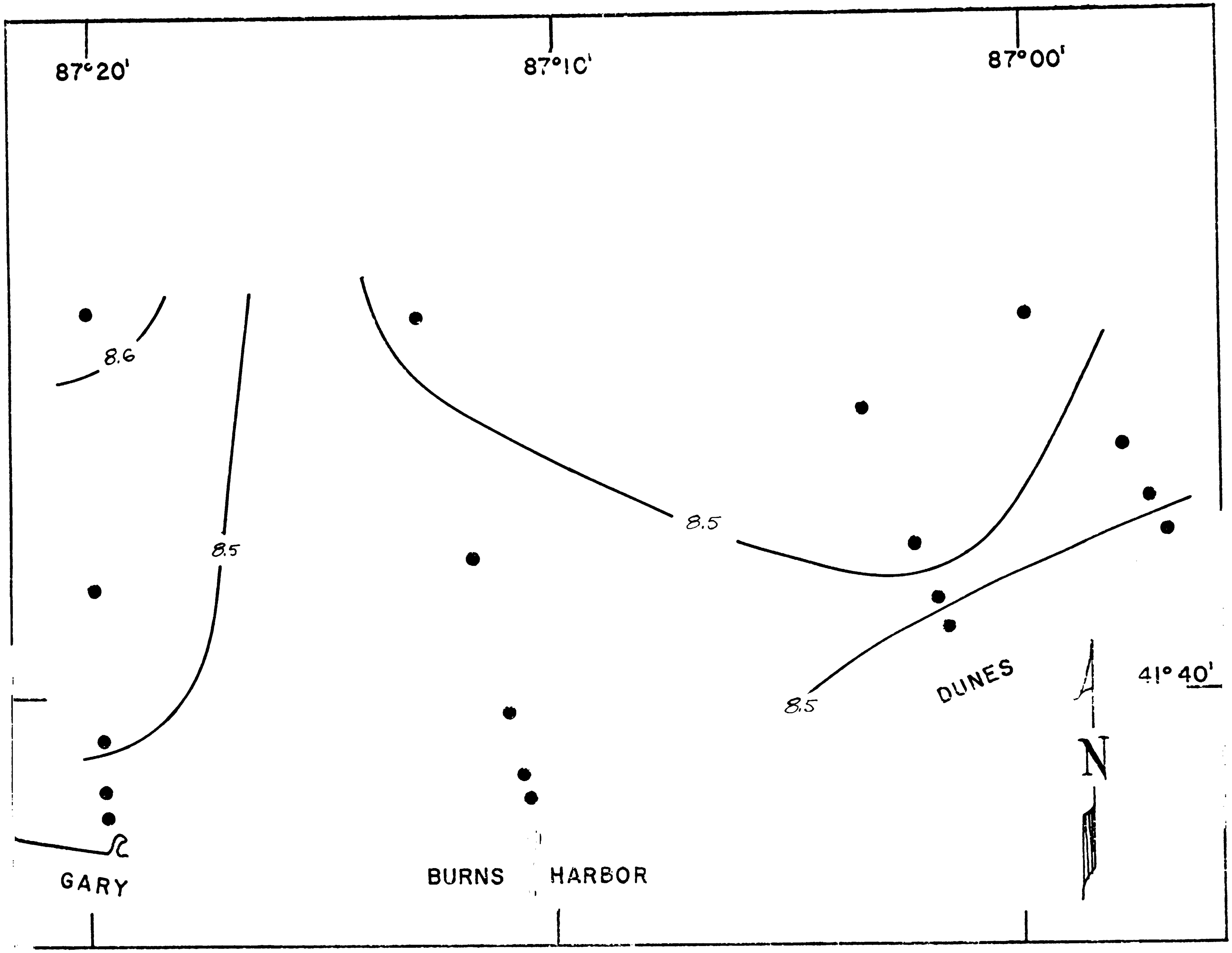
Appendix Figure 8. Secchi disc contours, southern Lake Michigan; 20 August, 1977.



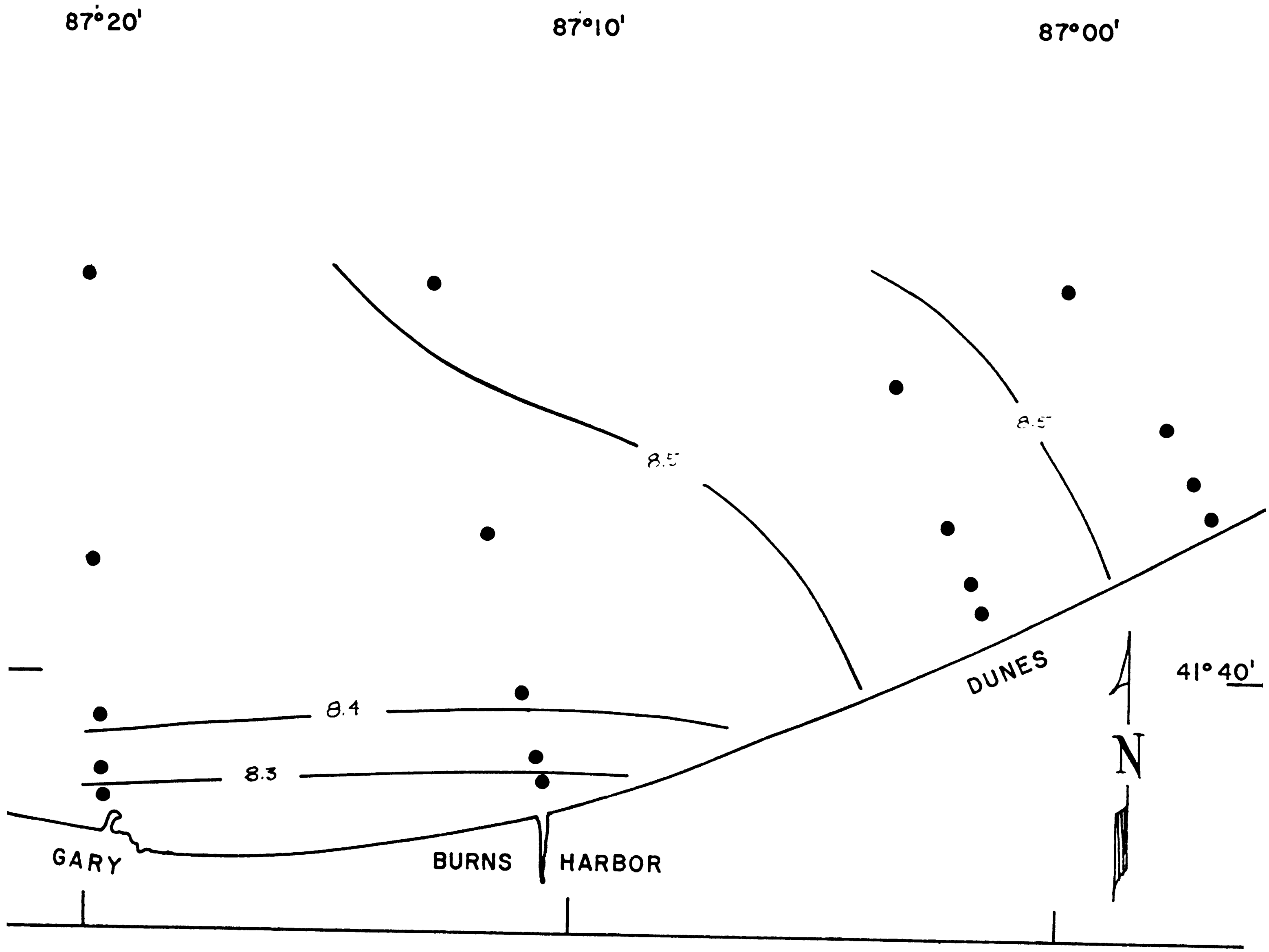
Appendix Figure 9. Secchi disc contours, southern Lake Michigan; 24 September, 1977.



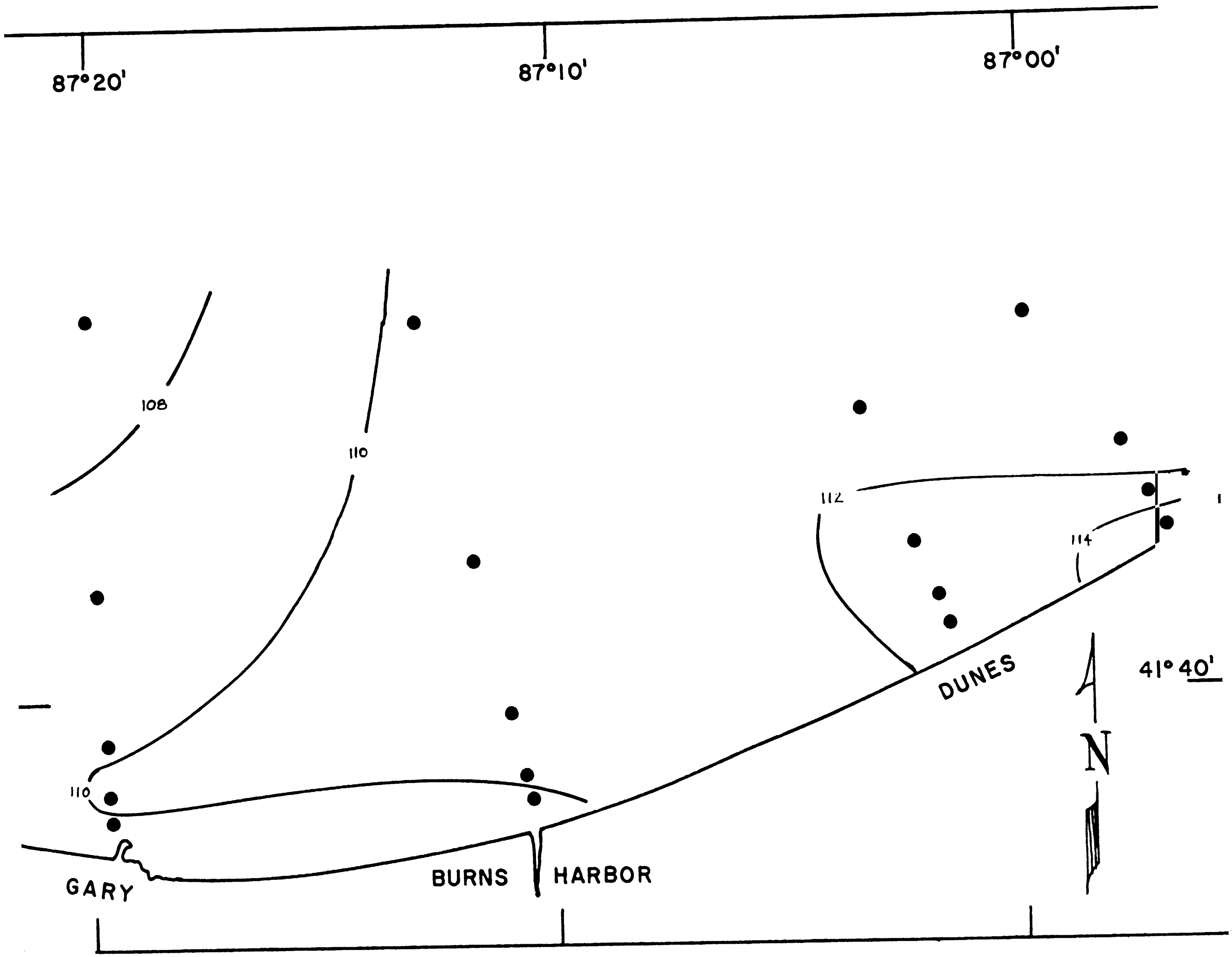
Appendix Figure 10. Contours for pH, southern Lake Michigan; 11 June, 1977.



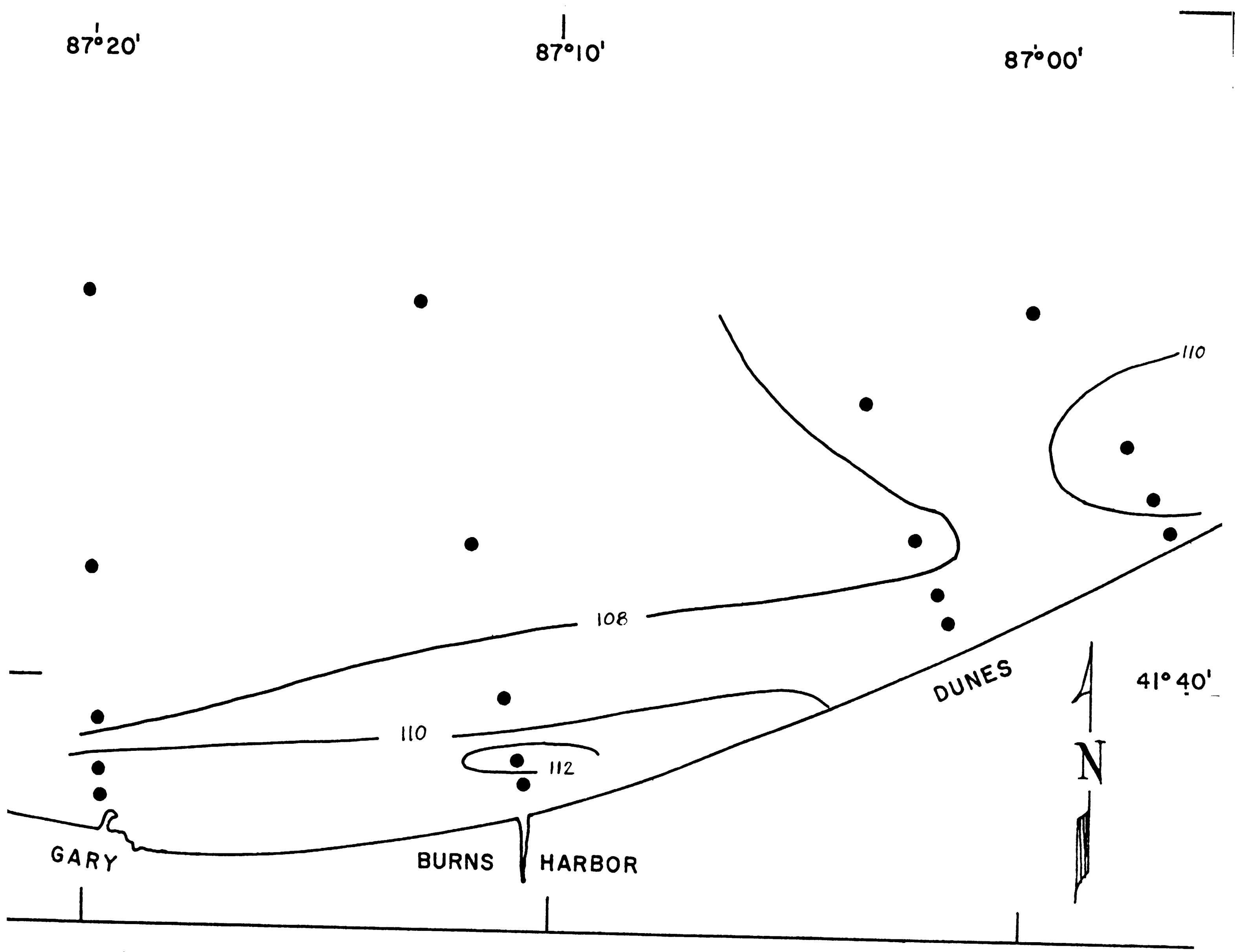
Appendix Figure 11. Contours for pH, southern Lake Michigan; 20 August, 1977.



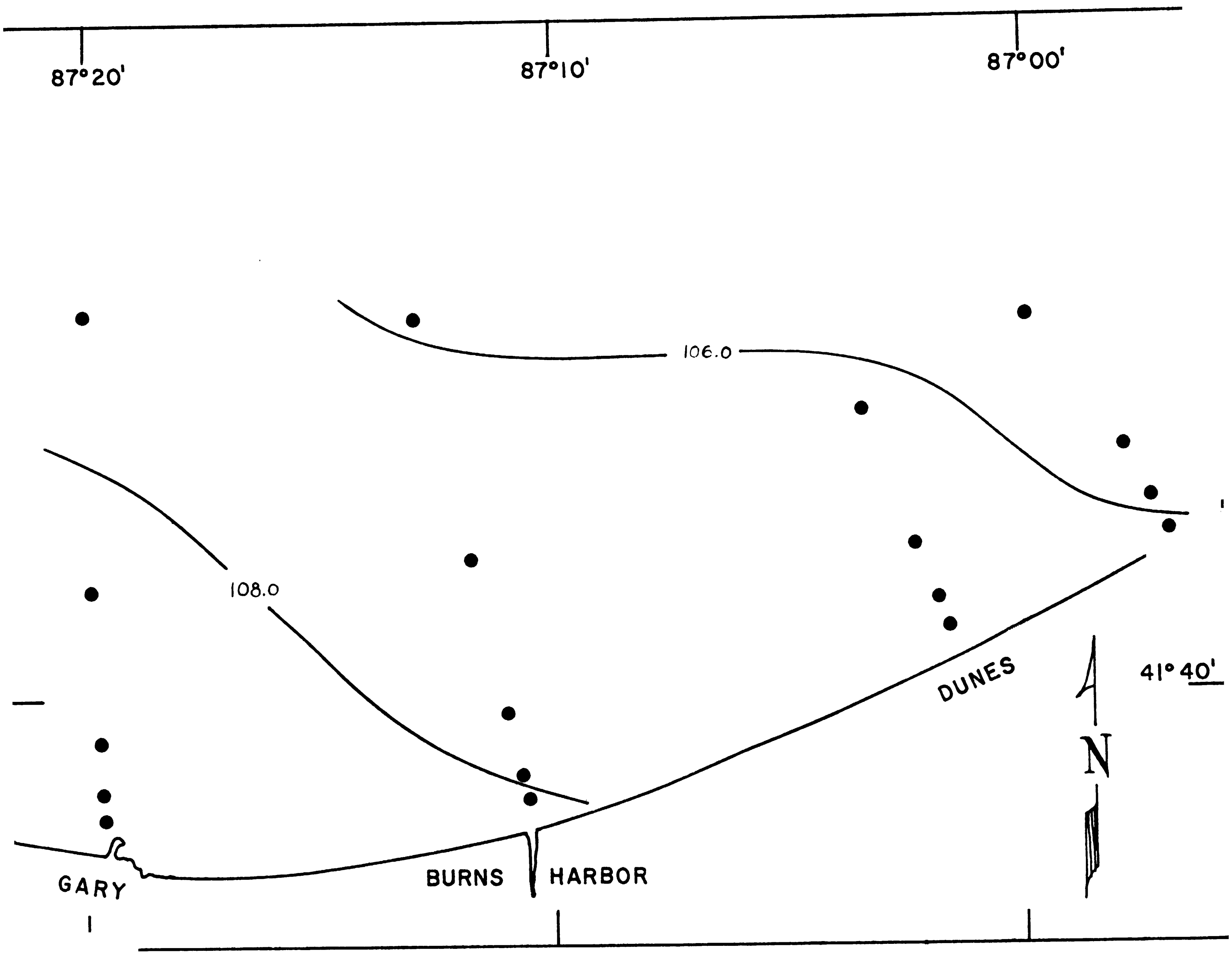
Appendix Figure 12. Contours for pH, southern Lake Michigan; 24 September, 1977.



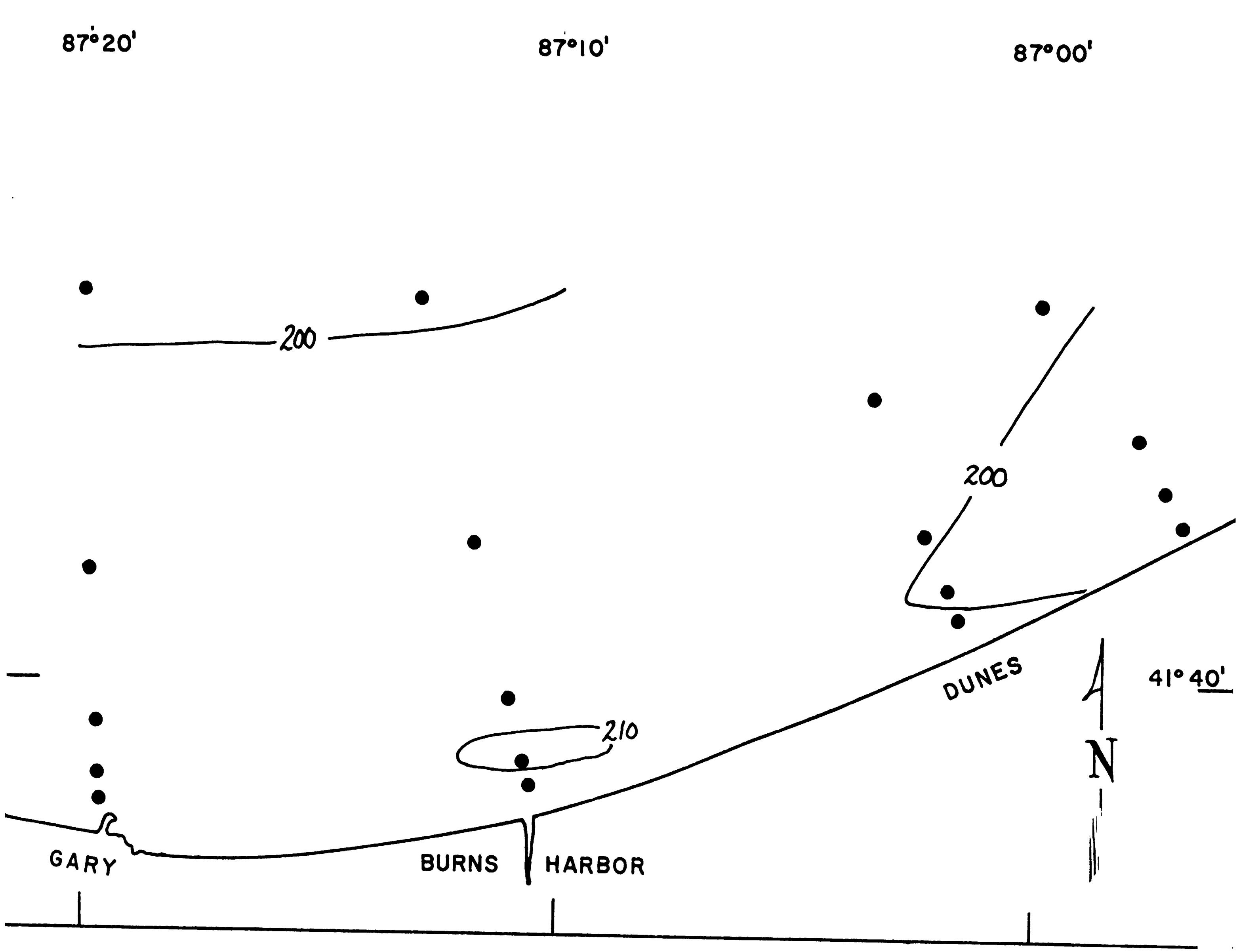
Appendix Figure 13. Alkalinity contours, southern Lake Michigan; 11 June, 1977.



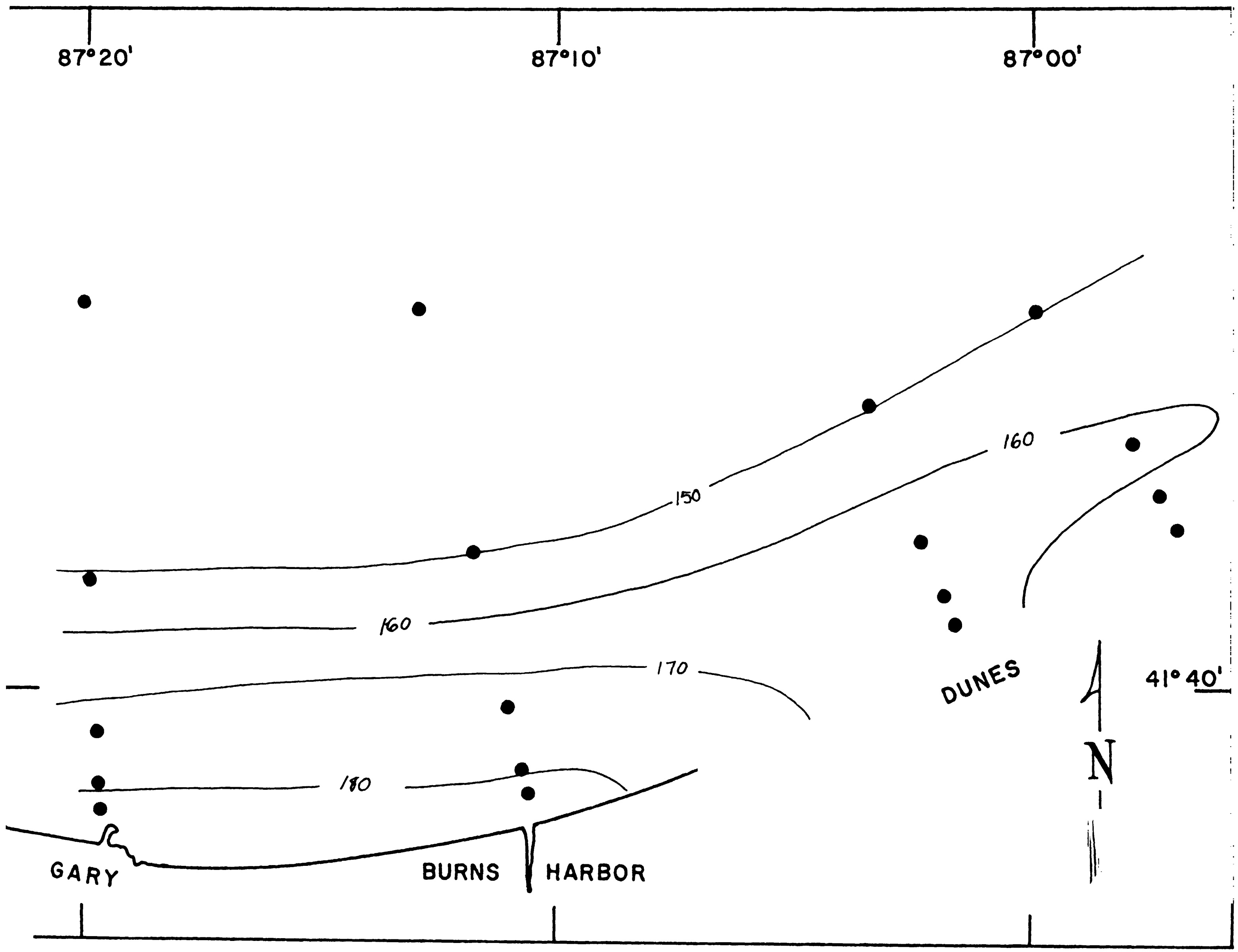
Appendix Figure 14. Alkalinity contours, southern Lake Michigan; 20 August, 1977.



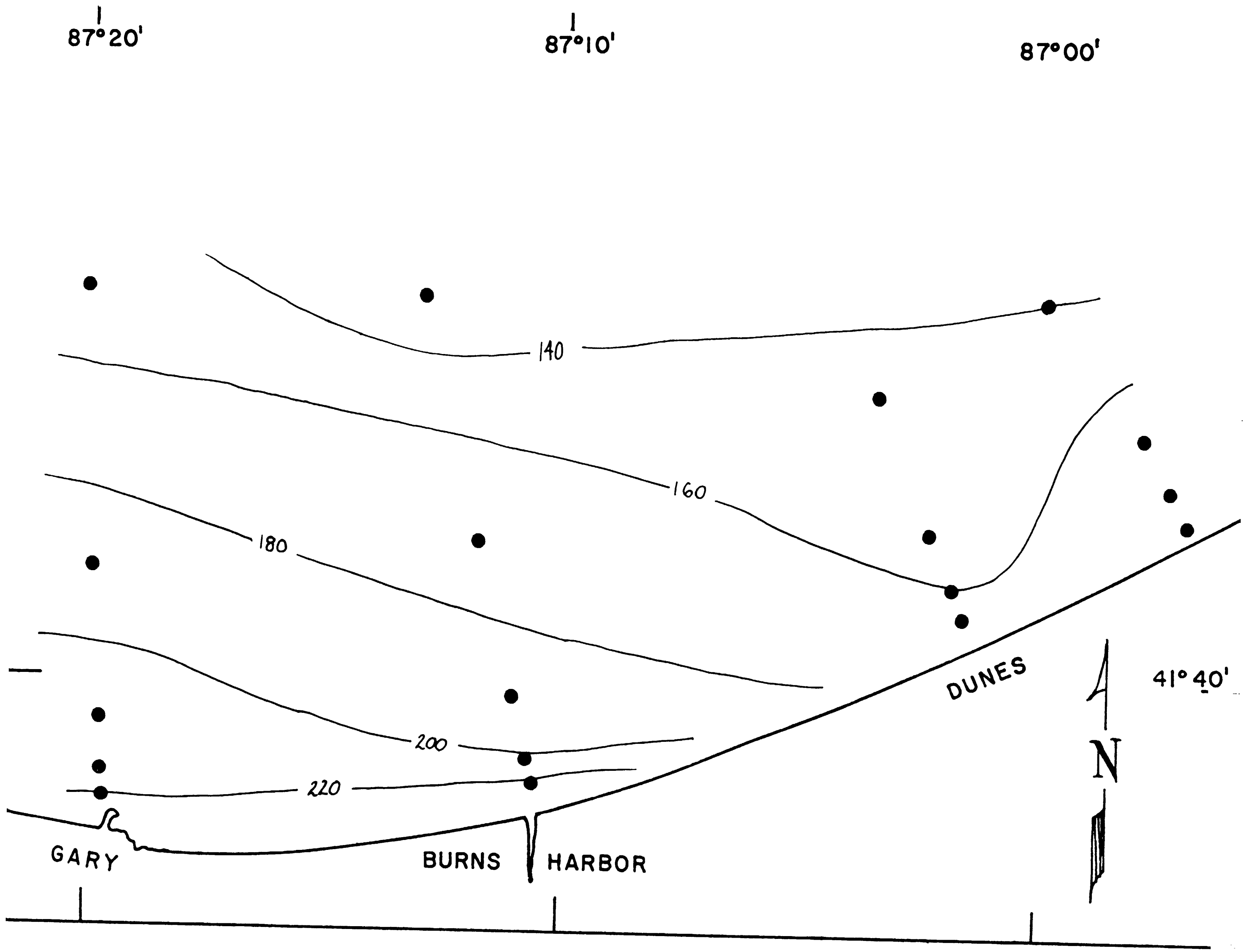
Appendix Figure 15. Alkalinity contours, southern Lake Michigan; 24 September, 1977.



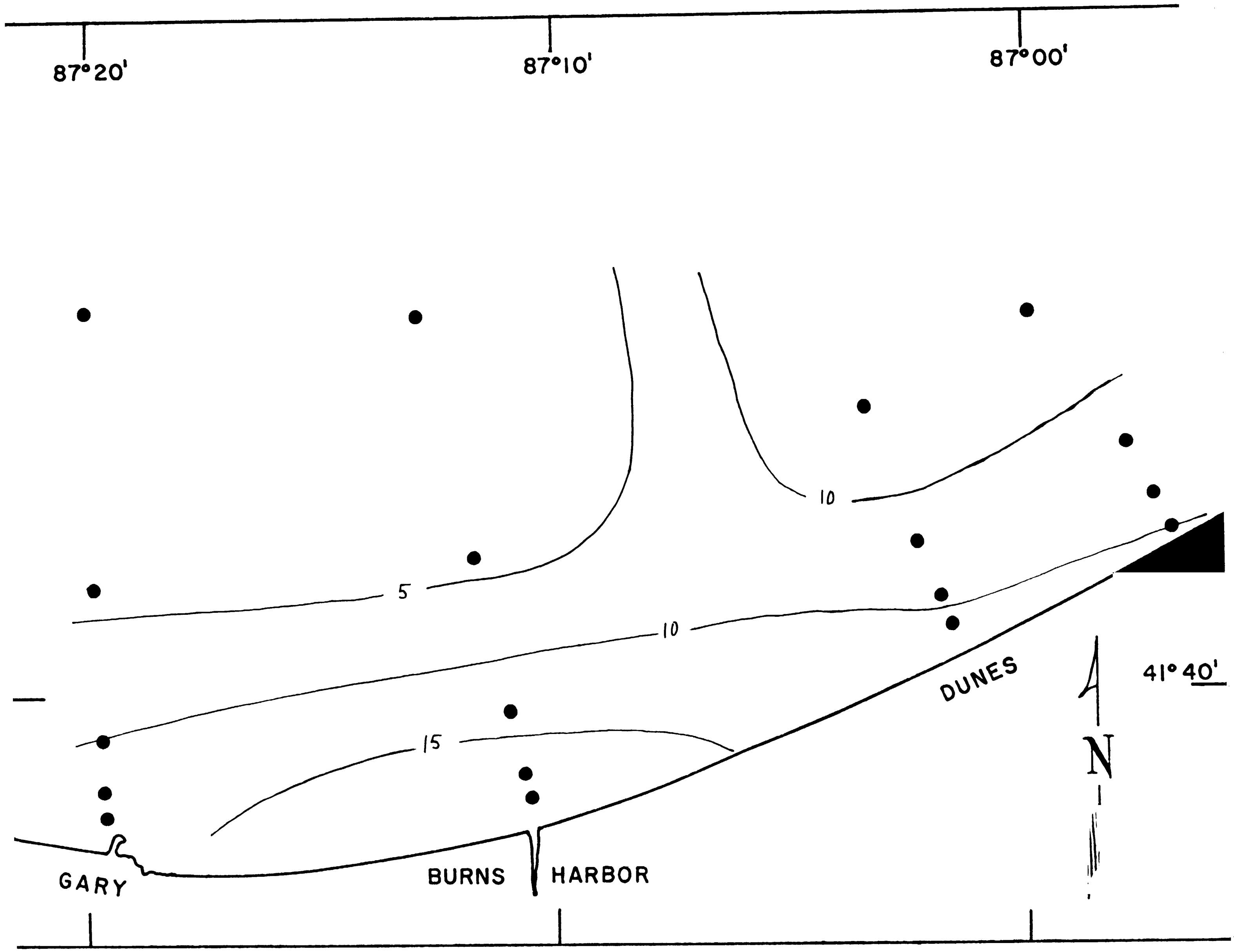
Appendix Figure 16. NO_3-N contours, southern Lake Michigan; 11 June, 1977.



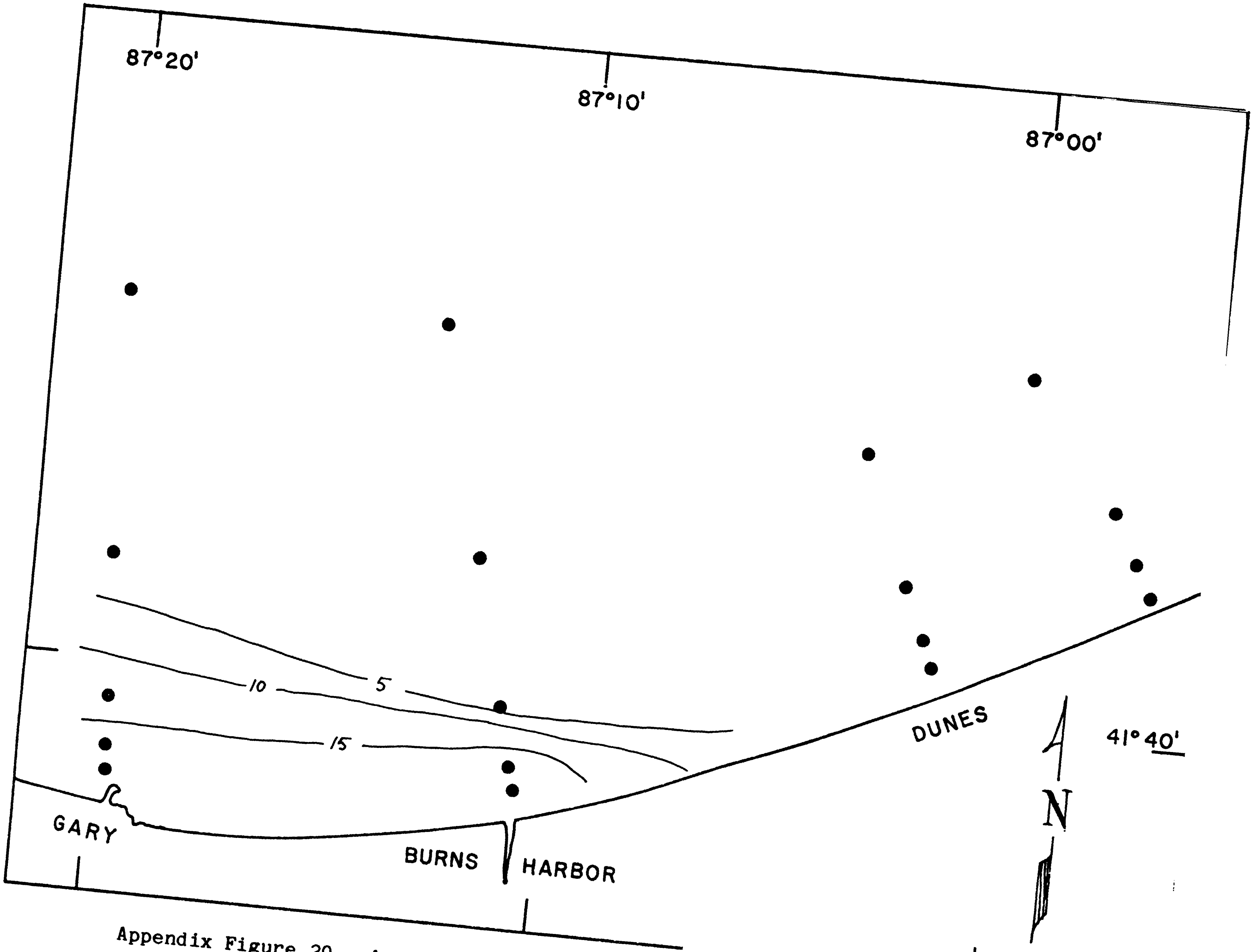
Appendix Figure 17. NO_3-N contours, southern Lake Michigan; 20 August, 1977.



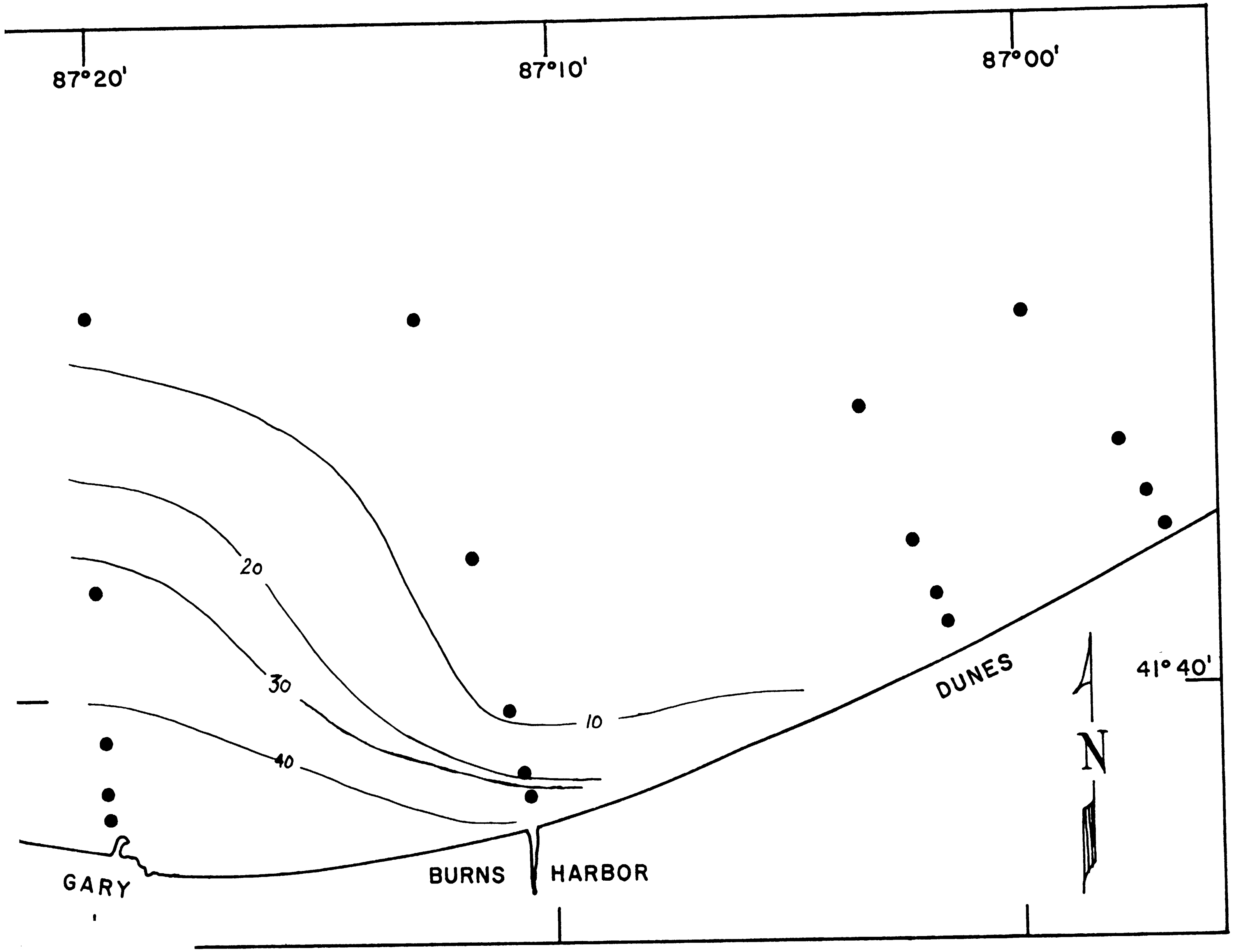
Appendix Figure 18. NO_3-N contours, southern Lake Michigan; 24 September, 1977.



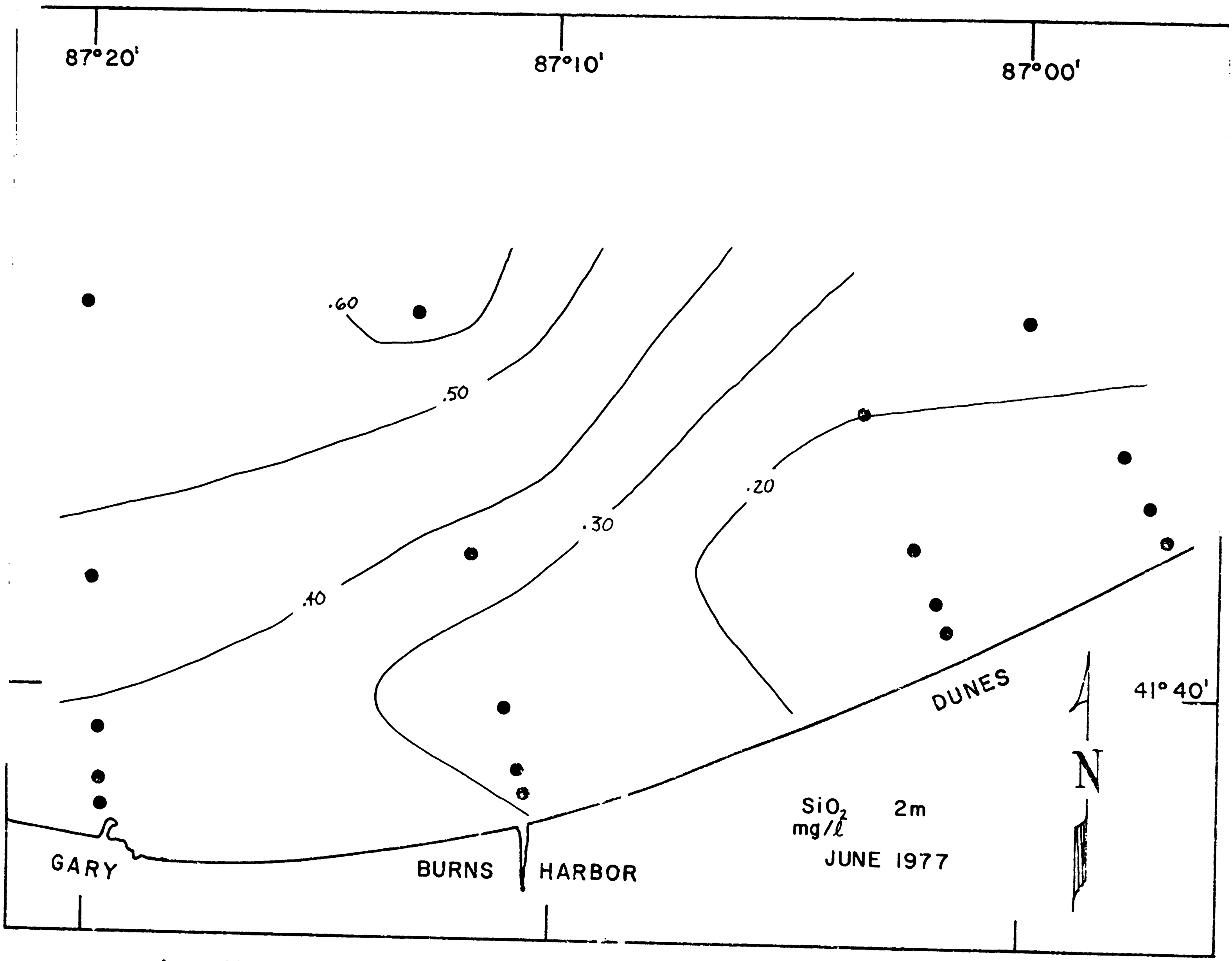
Appendix Figure 19. Ammonia contours, southern Lake Michigan; 11 June, 1977.



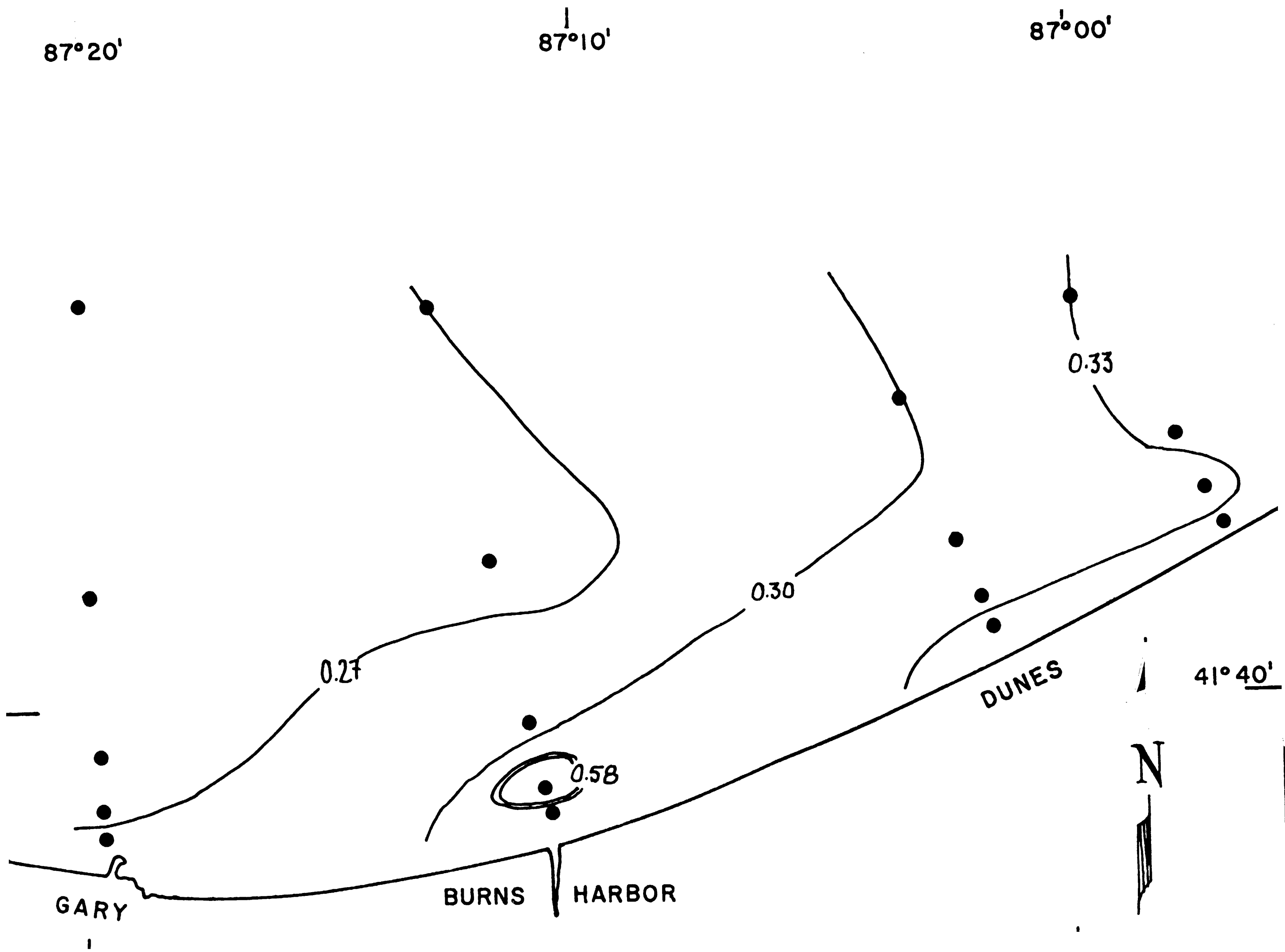
Appendix Figure 20. Ammonia contours, southern Lake Michigan; 20 August, 1977.



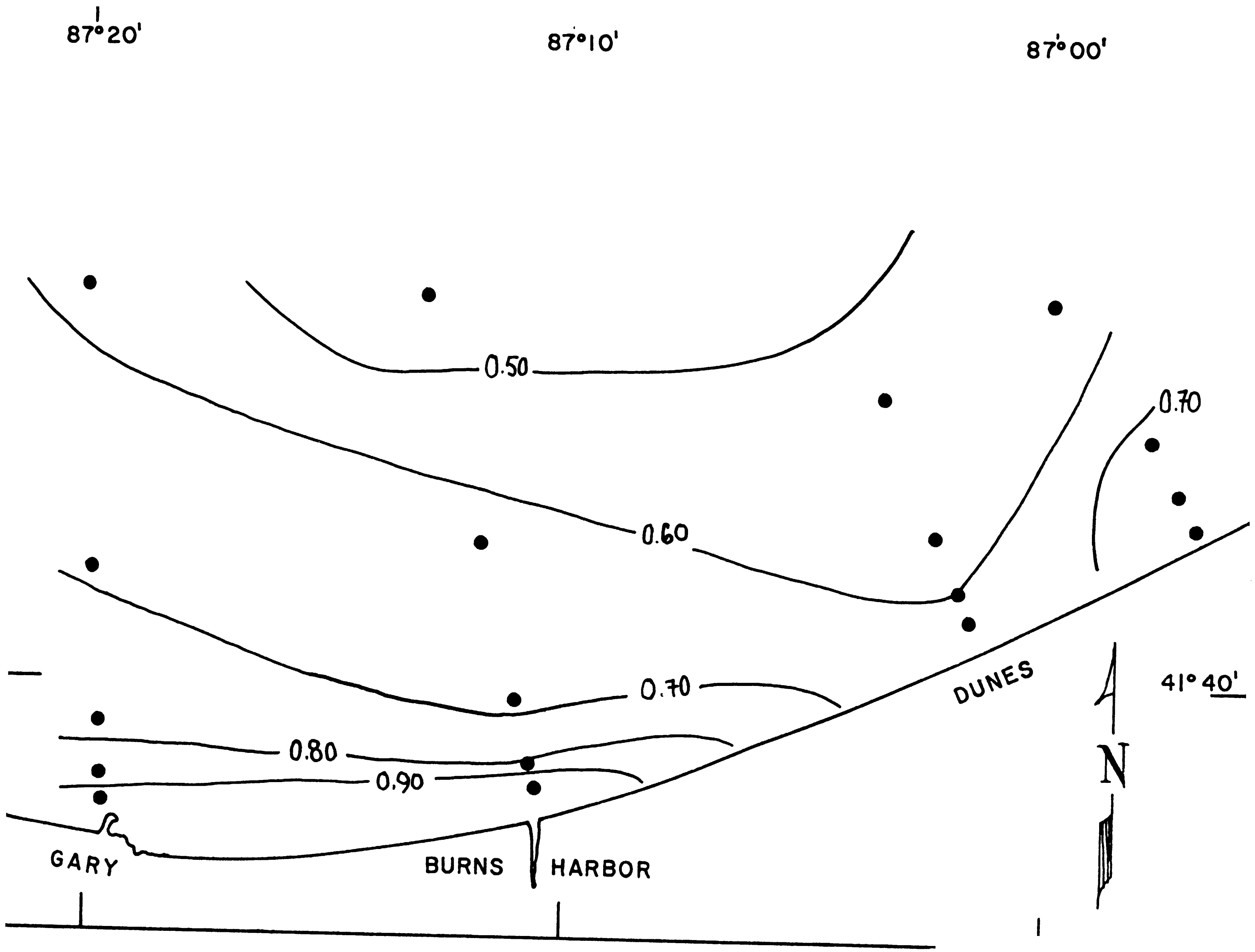
Appendix Figure 21. Ammonia contours, southern Lake Michigan; 24 September, 1977.



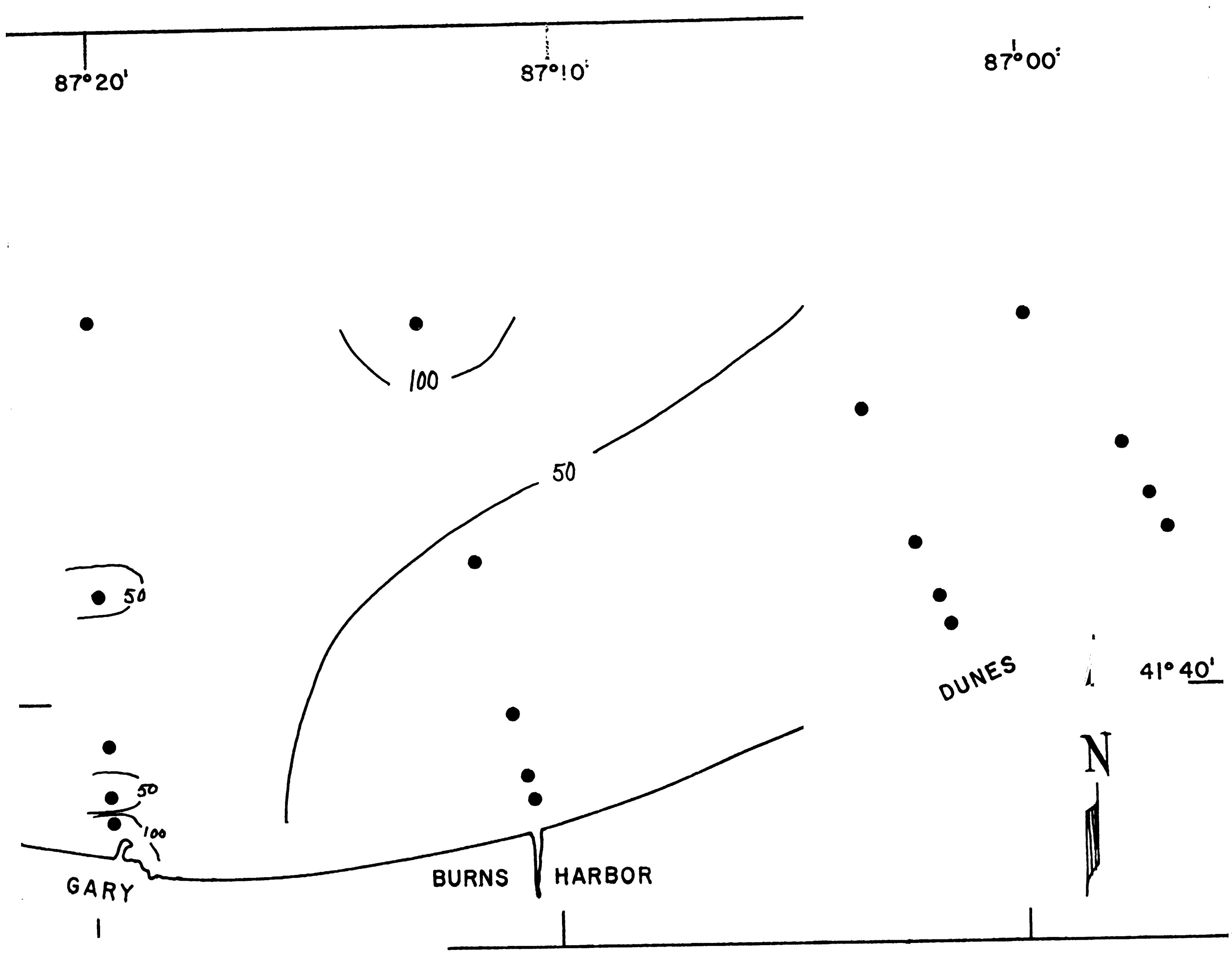
Appendix Figure 22. Silica contours, southern Lake Michigan; 11 June, 1977.



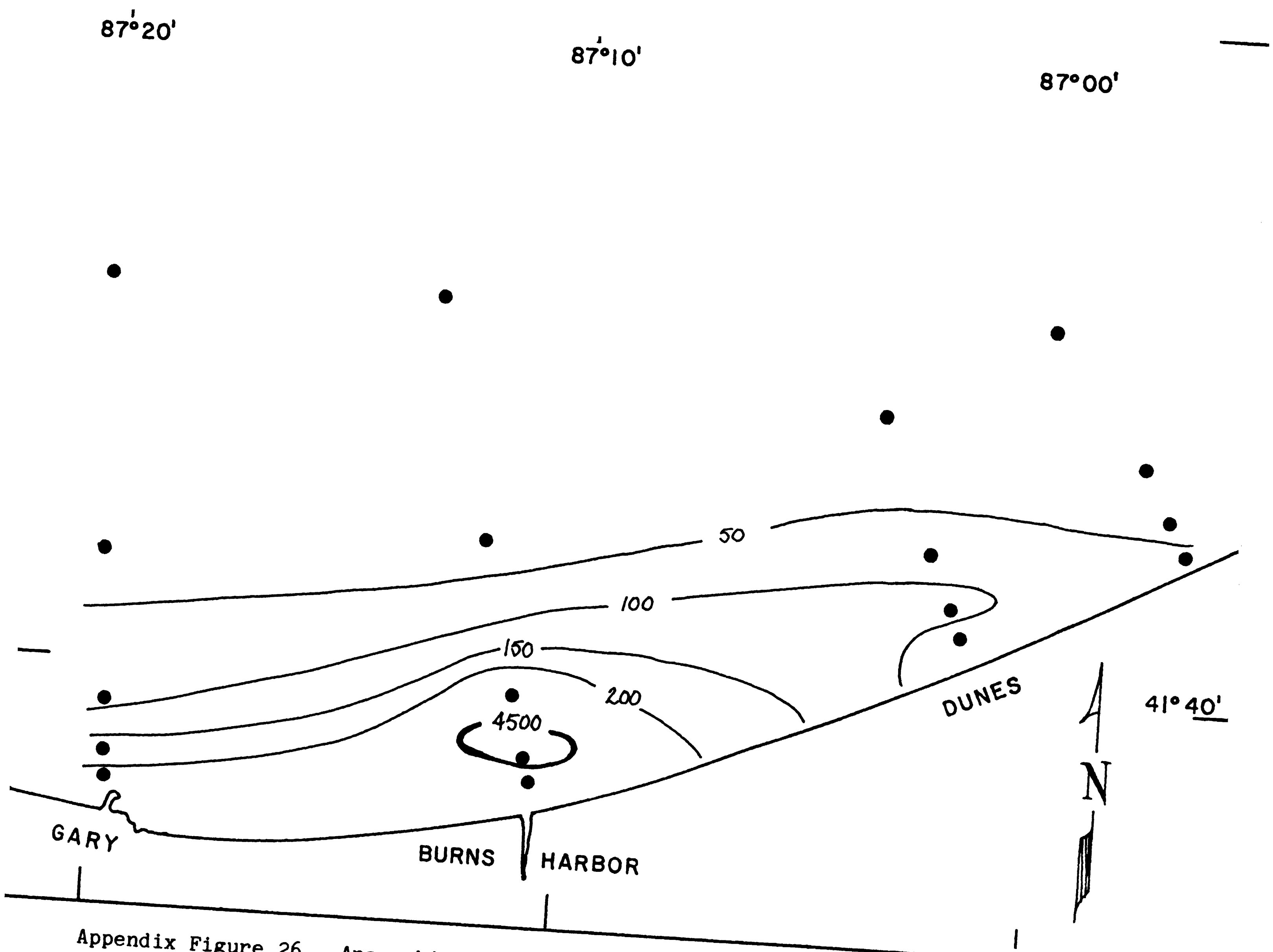
Appendix Figure 23. Silica contours, southern Lake Michigan; 20 August, 1977.



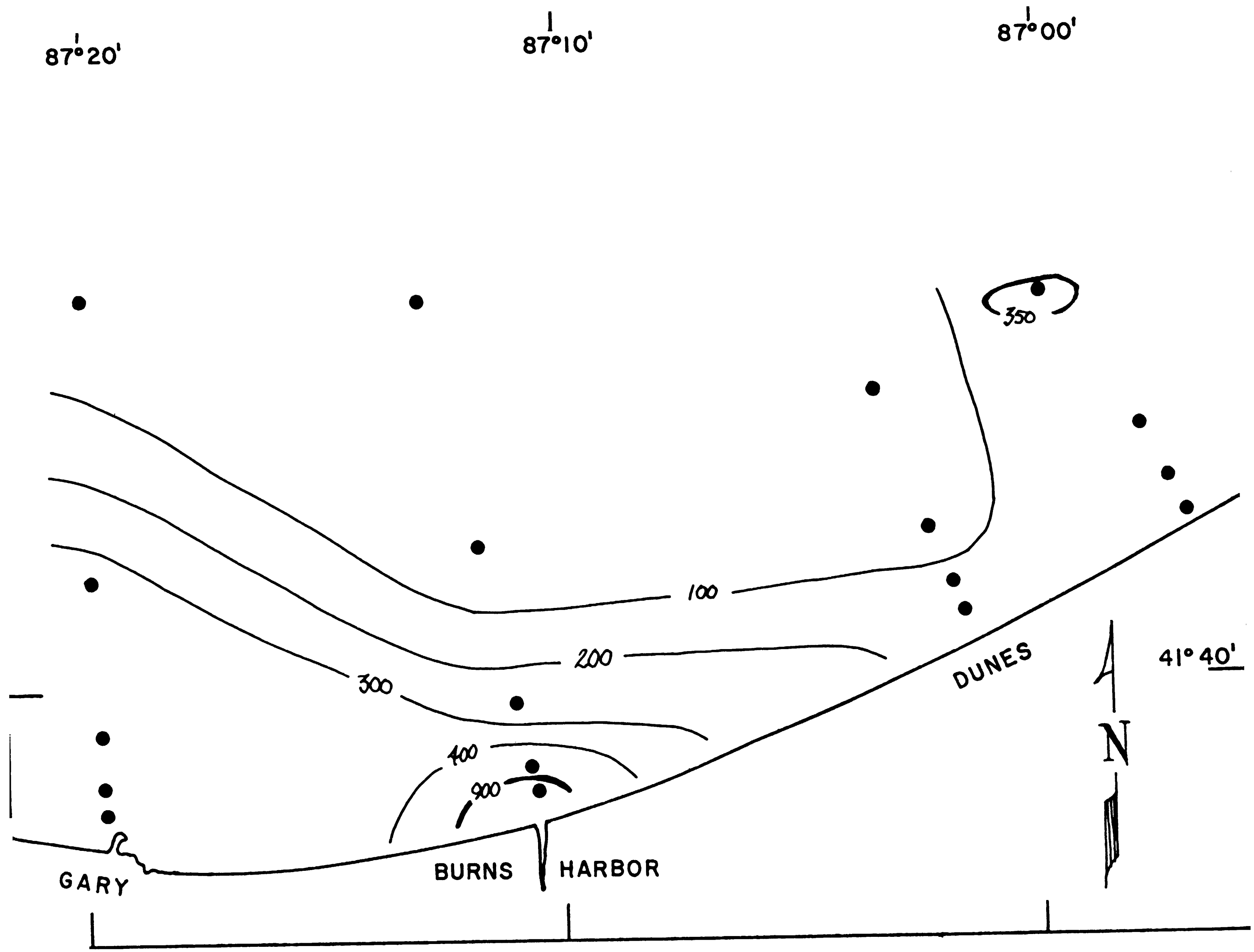
Appendix Figure 24. Silica contours, southern Lake Michigan; 24 September, 1977.



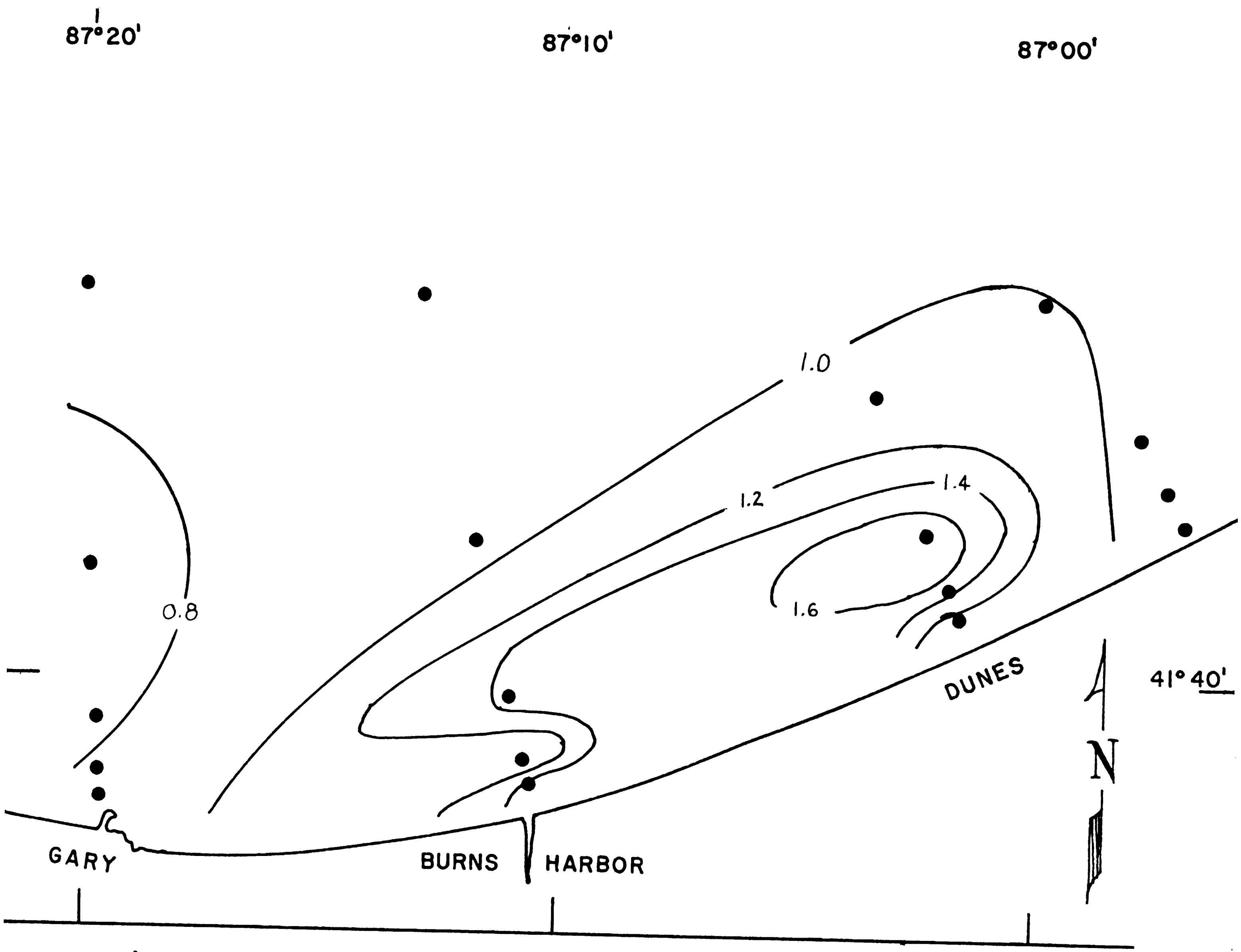
Appendix Figure 25. Anaerobic heterotroph contours, southern Lake Michigan; 11 June, 1977.



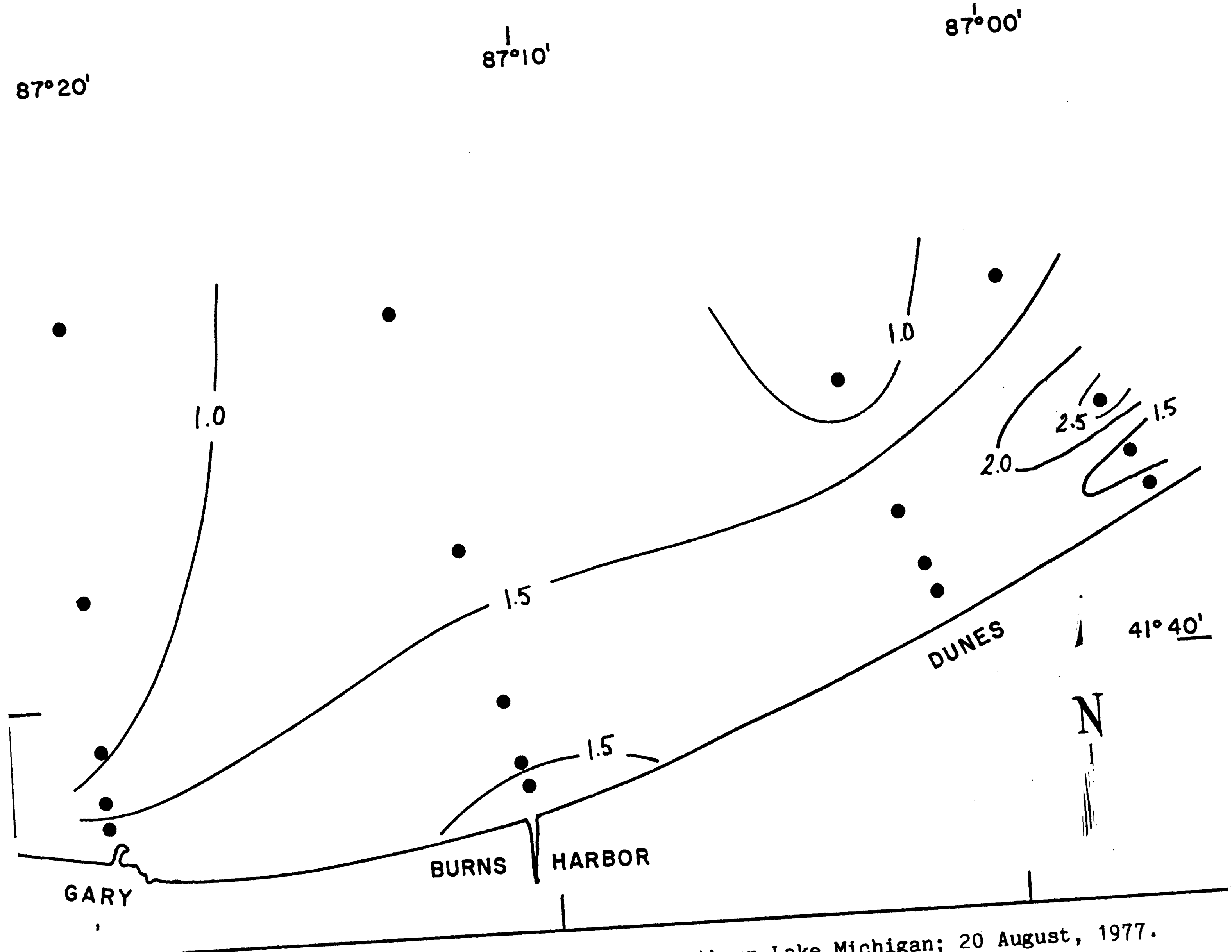
Appendix Figure 26. Anaerobic heterotroph contours, southern Lake Michigan; 20 August, 1977.



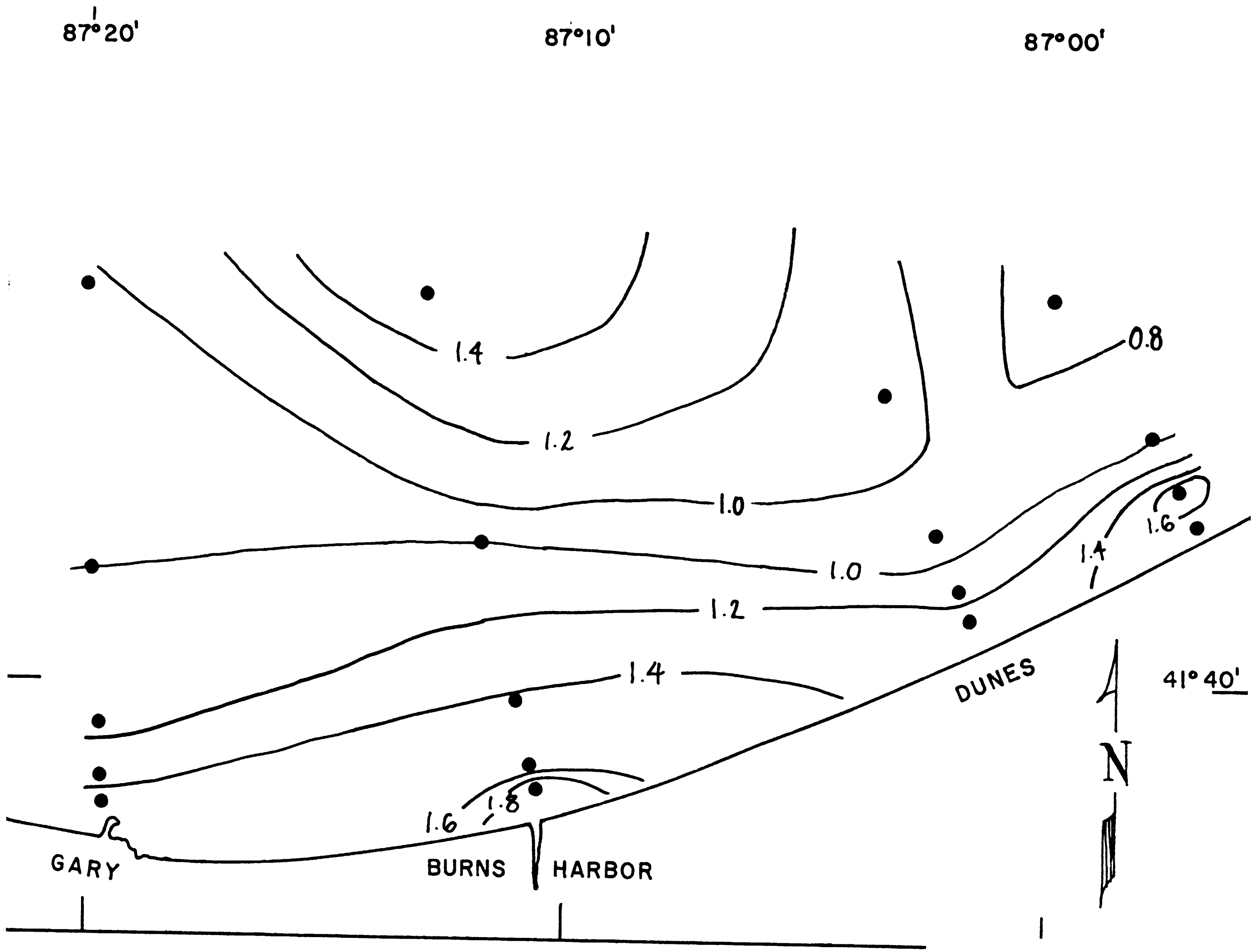
Appendix Figure 27. Anaerobic heterotroph contours, southern Lake Michigan; 24 September, 1977.



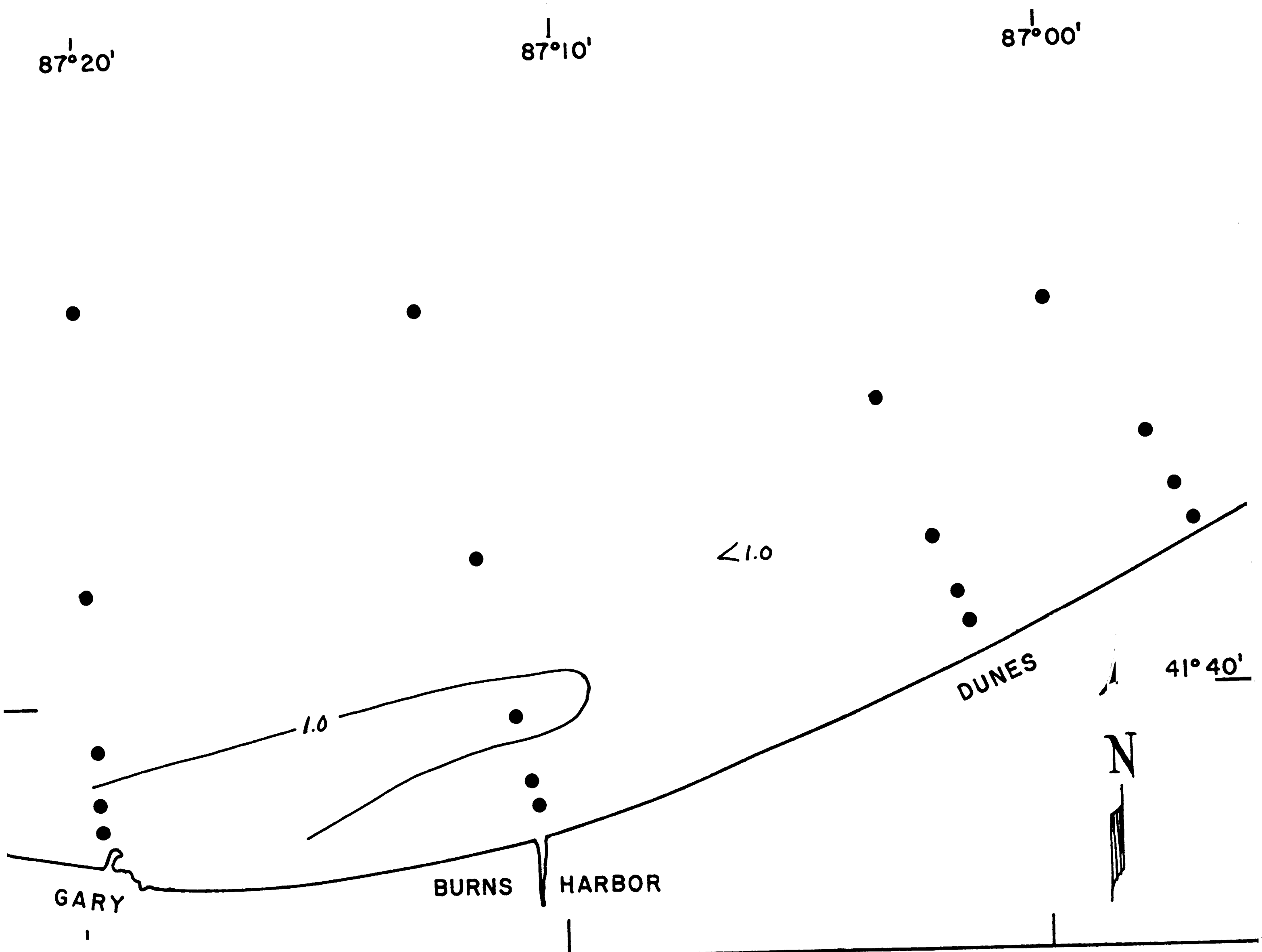
Appendix Figure 28. Turbidity contours, southern Lake Michigan; 11 June, 1977.



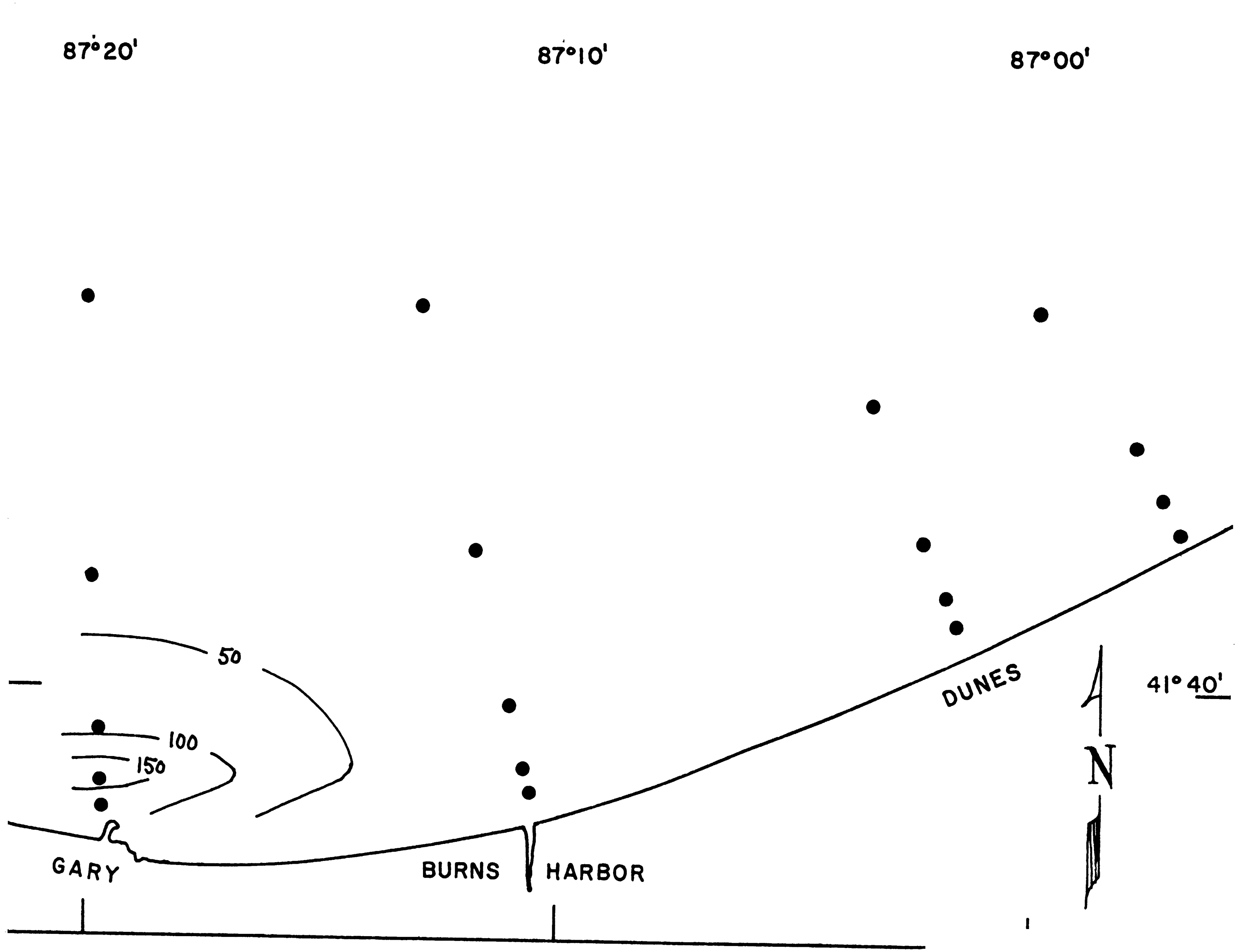
Appendix Figure 29. Turbidity contours, southern Lake Michigan; 20 August, 1977.



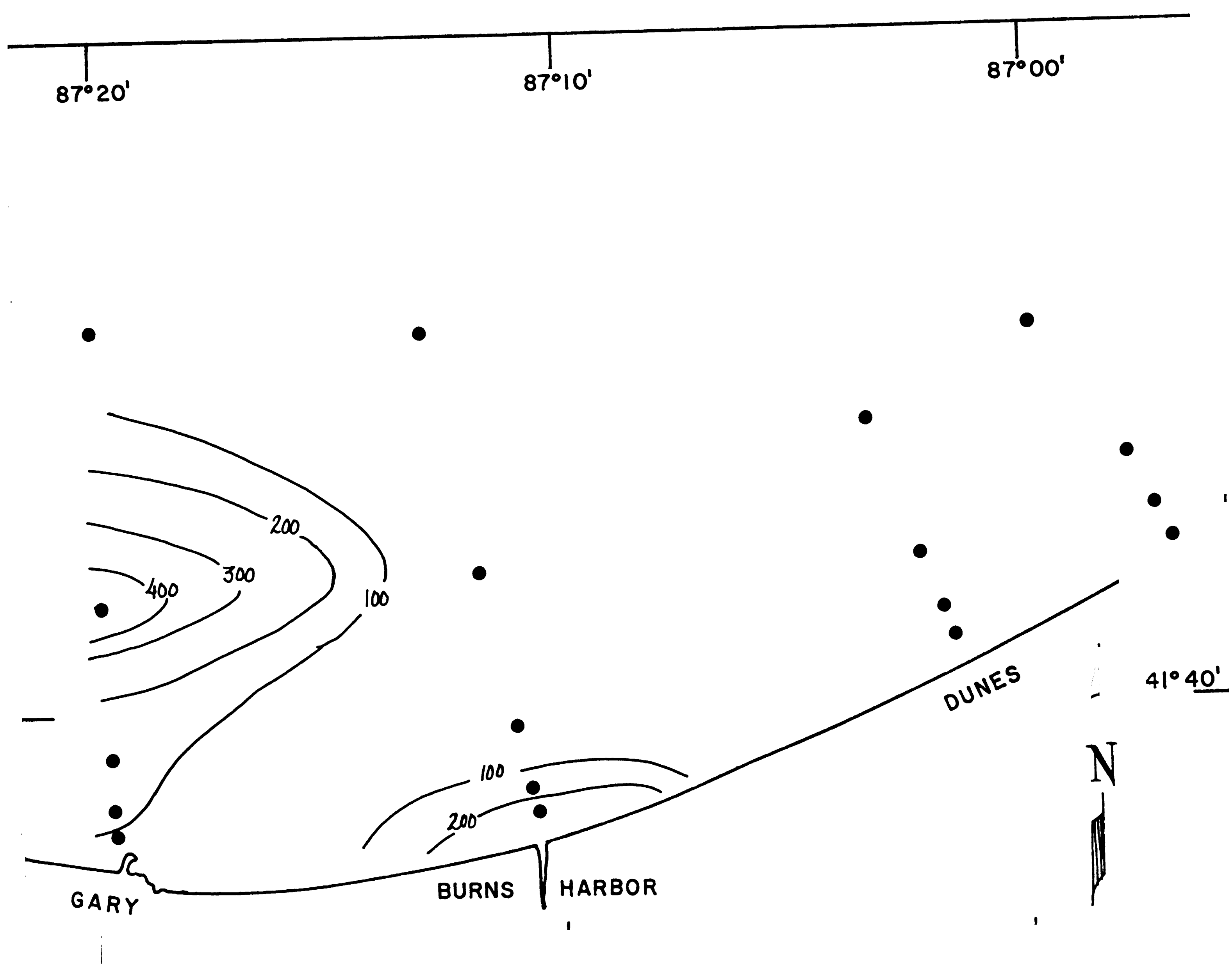
Appendix Figure 30. Turbidity contours, southern Lake Michigan; 24 September, 1977.



Appendix Figure 31. Fecal coliform contours, southern Lake Michigan, 11 June, 1977.



Appendix Figure 32. Fecal coliform contours, southern Lake Michigan, 20 August, 1977.



Appendix Figure 33. Fecal coliform contours, southern Lake Michigan, 24 September, 1977.

APPENDIX TABLE 1. Summary of phytoplankton species occurrence in the near-surface waters of southern Lake Michigan during 1977 sampling season. Summary is based on all samples analyzed. Summary includes the total number of samples in which a given taxon was noted, the average population density (cells/ml), the average relative abundance (% of assemblage), the maximum population density encountered (cells/ml), and the maximum relative abundance (% of assemblage) encountered.

	#	Average		Maximum	
	slides	cells/ml	% pop	cells/ml	% pop
CYANOPHYTA					
Anabaena flos-aquae (Lyngb.) Bréb.	29	24.458	0.640	335.103	7.045
Anabaena sp.	1	0.372	0.012	33.510	1.047
Anabaena spp.	1	0.419	0.011	37.699	1.030
A. subcylindrica Borge	3	0.605	0.009	33.510	0.391
Anacystis incerta (Lemm.) Dr. and Daily	70	1435.488	27.888	5443.328	63.185
A. thermalis (Menegh.) Dr. and Daily	62	86.288	1.844	295.309	8.338
Dactylococcopsis rhaphidioides Hansg.	27	2.397	0.060	23.038	0.654
Gomphosphaeria aponina Kütz.	5	2.653	0.071	62.832	1.507
G. lacustris Chod.	33	226.078	3.366	1748.819	21.305
Microcoleus spp.	1	1.257	0.035	113.097	3.125
Oscillatoria bornetii Zukal	61	275.063	7.683	1283.863	36.015
O. retzii Ag.	2	2.048	0.048	94.248	3.197
Oscillatoria sp.	12	4.328	0.063	94.248	1.752
Oscillatoria spp.	17	5.050	0.088	169.646	3.024
Schizothrix sp.	11	0.698	0.012	14.661	0.308
Schizothrix spp.	8	0.768	0.024	27.227	0.921
Total for Division (16 species)		2067.968	41.854		
CHLOROPHYTA					
Ankistrodesmus falcatus (Corda) Ralfs	28	1.862	0.059	18.850	0.661
A. gelifactum (Chod.) Bourr.	4	0.186	0.006	4.189	0.180
Ankistrodesmus sp. #3	14	0.652	0.017	12.566	0.282
Ankistrodesmus sp. #6	3	0.140	0.004	6.283	0.157
Ankistrodesmus sp.	1	0.047	0.001	4.189	0.121
Ankistrodesmus spp.	64	9.401	0.195	56.549	1.044
Ankyra spp.	1	0.047	0.001	4.189	0.122
Chlamydomonas sp.	26	107.930	1.443	1212.654	12.725
Chlamydomonas spp.	22	64.903	1.620	772.831	16.698
Coelastrum sp.	2	0.559	0.011	33.510	0.838
Cosmarium sp.	12	0.419	0.006	6.283	0.078
Cosmarium spp.	7	0.209	0.007	4.189	0.192
Crucigenia irregularis Wille	13	3.002	0.056	69.115	0.972
C. quadrata Morren	25	11.380	0.208	167.551	4.676
C. rectangularis (A. Braun) Gay	9	2.234	0.028	35.605	0.495
C. tetrapedia (Kirch.) West and West	3	0.559	0.011	33.510	0.495
Dictyosphaerium ehrenbergianum Naegeli	1	1.443	0.022	129.852	2.016
Elakatothrix gelatinosa Wille	7	0.396	0.005	12.566	0.176

(continued).

APPENDIX TABLE 1 (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Franceia droescheri (Lemm.) G. M. Smith	7	0.186	0.004	4.189	0.088
Gloeocystis planctonica (W. and W.) Lemm.	86	123.545	3.168	513.126	8.687
Golenkinia radiata (Chod.) Wille	2	0.093	0.002	6.283	0.156
Kirchneriella contorta (Schmidle) Bohlin	4	0.326	0.011	18.850	0.542
K. elongata G. M. Smith	23	1.769	0.039	23.038	0.539
K. lunaris (Kirch.) Moebius	1	0.186	0.003	16.755	0.312
Kirchneriella sp.	4	0.140	0.004	6.283	0.181
Kirchneriella spp.	19	1.443	0.041	20.944	0.663
K. subsolitaria G. S. West	1	0.093	0.002	8.378	0.220
Lagerheimia ciliata (Lag.) Chod.	12	0.512	0.011	8.378	0.208
L. subsalsa Lemm.	2	0.093	0.002	6.283	0.188
Micractinium sp.	1	0.745	0.006	67.021	0.555
Mougeotia sp.	12	0.908	0.021	10.472	0.327
Mougeotia sp. #1	1	0.279	0.026	25.133	2.299
Mougeotia spp.	5	0.559	0.017	18.850	0.587
Nephrocytium agardhianum Näg.	7	0.908	0.022	23.038	0.635
N. obesum West and West	1	0.093	0.003	8.378	0.294
Nephrocytium sp.	2	0.279	0.003	16.755	0.176
Nephrocytium spp.	2	0.209	0.007	12.566	0.446
Oocystis pusilla Hansg.	1	0.582	0.013	52.360	1.174
Oocystis sp.	1	0.023	0.001	2.094	0.055
Oscystis spp.	61	30.881	0.567	263.894	3.002
Pediastrum duplex Meyen	3	1.978	0.036	92.153	1.686
P. duplex var. *clathratum* (A. Braun) Lag.	1	0.186	0.005	16.755	0.463
P. obtusum Lucks	1	0.186	0.004	16.755	0.378
P. simplex var. *duodenarium* (Bailey) Raben.	1	0.512	0.014	46.077	1.283
P. tetras (Ehr.) Ralfs	7	1.373	0.036	33.510	0.790
Pedinomonas minutissima Skuja	2	0.349	0.011	27.227	0.851
Quadrigula sp.	1	0.047	0.001	4.189	0.130
Scenedesmus acuminatus (Lag.) Chod.	26	4.049	0.099	41.888	0.932
S. acutus f. *costulatus* (Chod.) Uherkov.	4	0.745	0.019	16.755	0.719
S. acutus Meyen	4	0.349	0.009	8.378	0.251
S. arcuatus Lemm.	3	0.326	0.008	12.566	0.330
S. armatus var. *boglariensis* Hortob.	2	0.186	0.003	8.378	0.130
S. bicaudatus (Hansg.) Chod.	1	0.047	0.001	4.189	0.099
S. bijuga var. *alternans* (Reinsch) Hansg.	1	0.186	0.002	16.755	0.176
S. bijuga (Turp.) Lag.	9	1.001	0.038	41.888	1.204
S. brasiliensis Bohlin	2	0.279	0.007	16.755	0.455
S. carinatus (Lemm.) Chod.	2	0.186	0.003	8.378	0.202

(continued).

APPENDIX TABLE 1 (continued).

	# slides	Average cells/ml	% pop	Maximum cells/ml	% pop
Scenedesmus dispar Bréb.	1	0.093	0.003	8.378	0.235
S. quadricauda (Turp.) Bréb.	54	8.866	0.227	58.643	1.802
S. quadricauda var. *longispina* (Chod.) G.M. Smith	18	2.560	0.114	25.133	2.978
Scenedesmus sp.	1	0.047	0.001	4.189	0.060
Scenedesmus spinosus Chod.	12	0.884	0.020	8.378	0.234
Scenedesmus spp.	73	17.686	0.454	92.153	2.730
Schroederia sp.	1	0.023	0.000	2.094	0.017
Selenastrum sp.	2	0.070	0.002	4.189	0.121
Selenastrum spp.	2	0.116	0.004	8.378	0.278
Staurastrum sp.	2	0.047	0.001	2.094	0.033
Tetraedrom caudatum (Corda) Hansg.	4	0.116	0.003	4.189	0.100
T. minimum (A. Braun) Hansg.	30	1.280	0.027	14.661	0.326
T. regulare Kuetzing	1	0.023	0.000	2.094	0.041
Ulothrix sp.	2	0.628	0.011	37.699	0.589
Undetermined green colony	3	0.489	0.013	23.038	0.662
Undetermined green filament	1	0.093	0.003	8.378	0.231
Undetermined green filament #5	9	9.634	0.188	259.705	6.263
Undetermined green individual	77	13.008	0.349	90.059	3.640
Total for Division (75 species)		436.857	9.392		
BACILLARIOPHYTA					
Achnanthes clevei Grun.	9	0.233	0.005	4.189	0.098
A. lanceolata (Bréb.) Grun.	2	0.047	0.001	2.094	0.041
A. minutissima (Kütz.)	3	0.070	0.002	2.094	0.071
A. recurvata ?	6	0.233	0.007	10.472	0.289
Achnanthes sp.	7	0.209	0.005	4.189	0.118
Achnanthes spp.	2	0.047	0.002	2.094	0.095
Amphipleura pellucida Kütz.	27	1.629	0.032	16.755	0.350
Amphora neglecta Stoerm. and Yang	1	0.047	0.001	4.189	0.117
A. ovalis var. *pediculus* (Kütz.) V. H.	1	0.023	0.001	2.094	0.075
A. ovalis Kütz.	3	0.070	0.002	2.094	0.087
A. perpusilla Grun.	24	0.698	0.019	4.189	0.248
Amphora spp.	1	0.023	0.001	2.094	0.052
Amphora subcostulata Stoerm. and Yang	2	0.047	0.001	2.094	0.060
Asterionella formosa Hass.	81	22.131	0.531	182.212	3.413
Cocconeis placentula Ehr.	1	0.023	0.000	2.094	0.022
Cocconeis sp. #2	1	0.023	0.003	2.094	0.248

(continued).

APPENDIX TABLE 1 (continued).

	# slides	Average		Maximum	
		cells/ml	% pop	cells/ml	% pop
Cyclotella atomus Hust.	10	0.279	0.007	4.189	0.094
C. comensis Grun.	90	86.754	1.930	418.879	5.347
C. comensis auxospore	24	1.117	0.024	14.661	0.228
C. comta auxospore	15	1.257	0.030	16.755	0.395
C. comta (Ehr.) Kütz.	61	5.027	0.096	54.454	0.473
C. cryptica Reimann, Lewin, and Guillard	49	7.330	0.186	180.118	4.245
C. kutzingiana Thw.	9	0.209	0.007	2.094	0.095
C. meneghiniana Kütz.	17	0.559	0.018	6.283	0.496
C. meneghiniana var. *plana* Fricke	31	1.466	0.048	33.510	1.084
C. michiganiana Skv.	25	0.931	0.025	8.378	0.271
C. ocellata Pant.	50	3.537	0.072	23.038	0.448
C. pseudostelligera Hust.	44	3.863	0.121	23.038	0.993
Cyclotella sp. #1	1	0.023	0.001	2.094	0.058
Cyclotella sp. #6	45	7.493	0.189	62.832	1.806
Cyclotella spp.	58	7.912	0.225	56.549	1.526
Cyclotella stelligera (Cl. and Grun.) V. H.	90	191.845	5.172	456.578	13.582
Cymatopleura elliptica (Bréb. and Godey) Wm. Smith	1	0.023	0.000	2.094	0.029
C. solea (Bréb. and Godey) Wm. Smith	7	0.163	0.004	2.094	0.073
Cymbella microcephala Grun.	6	0.256	0.008	8.378	0.348
C. prostrata var. *auerswaldii* (Rabh.) Reim.	4	0.093	0.003	2.094	0.090
Cymbella sp. #12	2	0.047	0.002	2.094	0.074
Cymbella sp.	2	0.047	0.000	2.094	0.022
Cymbella spp.	2	0.047	0.002	2.094	0.090
Diatoma ehrenbergii Kütz.	7	0.209	0.007	4.189	0.146
D. hiemale var. *mesodon* (Ehr.) Grun.	1	0.023	0.001	2.094	0.088
Diatoma sp.	1	0.023	0.000	2.094	0.037
Diatoma spp.	1	0.023	0.001	2.094	0.057
Diatoma tenue Ag.	10	0.489	0.013	16.755	0.483
D. tenue var. *elongatum* Lyngb.	29	2.630	0.086	31.416	0.916
D. tenue var. *pachycephala* Grun.	38	5.818	0.208	41.888	1.985
D. vulgare Bory	1	0.023	0.001	2.094	0.060
Diploneis oculata (Bréb.) Cl.	5	0.116	0.004	2.094	0.078
Entomoneis ornata (J. W. Bail.) Reim.	2	0.047	0.002	2.094	0.095
Fragilaria capucina Desm.	4	2.118	0.060	98.436	2.833
F. construens (Ehr.) Grun.	1	0.070	0.002	6.283	0.188
F. construens var. *binodis* (Ehr.) Grun.	1	0.023	0.001	2.094	0.059
F. construens var. *capitata* Hérib.	1	0.023	0.001	2.094	0.049
F. construens var. *minuta* Temp. and Per.	13	0.512	0.014	10.472	0.199

(continued).

APPENDIX TABLE 1 (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Fragilaria construens var. *venter* (Ehr.) Grun.	1	0.023	0.001	2.094	0.065
F. crotonensis Kitton	77	99.530	2.403	397.935	8.955
F. intermedia Grun.	13	6.260	0.158	92.153	2.564
F. intermedia var. *fallax* (Grun.) A. Cl.	10	3.398	0.124	100.531	3.493
F. pinnata Ehr.	8	1.978	0.046	75.398	2.260
Fragilaria sp.	14	0.559	0.010	8.378	0.131
Fragilaria spp.	7	0.628	0.012	25.133	0.343
Fragilaria vaucheriae (Kütz.) Peters.	10	0.396	0.014	6.283	0.285
Gomphonema dichotomum Kütz.	1	0.047	0.001	4.189	0.060
Gomphonema sp.	2	0.047	0.001	2.094	0.035
Gomphonema spp.	1	0.047	0.001	4.189	0.099
Mastogloia spp.	1	0.023	0.000	2.094	0.035
Melosira granulata var. *angustissima* O. Müll.	13	1.466	0.038	23.038	0.662
M. granulata (Ehr.) Ralfs	27	10.193	0.213	167.551	2.500
M. islandica O. Müll.	15	1.489	0.041	27.227	0.750
M. italica (Ehr.) Kütz.	57	10.000	0.302	56.549	1.985
M. varians Ag.	1	0.047	0.001	4.189	0.088
Navicula anglica var. *signata* Hust.	1	0.023	0.000	2.094	0.026
N. anglica var. *subsalsa* (Grun.) Cl.	24	0.908	0.033	10.472	0.496
N. capitata Ehr.	20	0.605	0.016	4.189	0.151
N. capitata var. *luneburgensis* (Grun.) Patr.	6	0.256	0.004	6.283	0.118
N. costulata Grun.	1	0.047	0.000	4.189	0.045
N. cryptocephala var. *veneta* (Kütz.) Rabh.	6	0.163	0.006	4.189	0.151
N. cryptocephala Kütz.	3	0.070	0.001	2.094	0.049
N. decussis Østr.	5	0.116	0.002	2.094	0.073
N. exiguiformis Hust.	10	0.233	0.005	2.094	0.068
N. gastriformis Hust.	1	0.023	0.001	2.094	0.058
N. luzonensis Hust.	1	0.023	0.000	2.094	0.045
N. menisculus var. *obtusa* Hust.	4	0.093	0.002	2.094	0.052
N. menisculus var. *upsaliensis* Grun.	2	0.047	0.001	2.094	0.049
N. platystoma var. *pantocsekii* Wislouchand Kolbe	1	0.023	0.000	2.094	0.041
N. pupula Kütz	7	0.163	0.004	2.094	0.075
N. pupula var. *mutata* (Krasske) Hust.	3	0.070	0.001	2.094	0.060
N. radiosa var. *tenella* (Bréb.) Grun.	5	0.140	0.005	4.189	0.176
N. radiosa Kütz	1	0.023	0.000	2.094	0.043
Navicula sp. #19	1	0.023	0.000	2.094	0.022
Navicula sp. #48	1	0.023	0.000	2.094	0.020
Navicula sp. #78	1	0.023	0.001	2.094	0.049

(continued).

APPENDIX TABLE 1 (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Navicula sp.	6	0.140	0.003	2.094	0.050
Navicula spp.	50	2.397	0.068	43.982	1.528
Navicula subhamulata Grun.	1	0.023	0.001	2.094	0.068
N. tripunctata (O. F. Müll.) Bory	2	0.047	0.001	2.094	0.033
N. viridula (Kütz.) Kütz.	1	0.023	0.001	2.094	0.052
Neidium dubium fo. *constrictum* Hust.	1	0.023	0.001	2.094	0.068
N. dubium var. #1	1	0.023	0.000	2.094	0.045
Neidium sp.	2	0.279	0.003	16.755	0.210
Neidium sp. #3	3	0.070	0.001	2.094	0.068
Neidium spp.	3	0.349	0.003	16.755	0.139
Nitzschia acicularis (Kütz.) Wm. Smith	76	18.919	0.474	85.870	1.898
N. acuta Hantz.	12	0.326	0.008	4.189	0.130
N. amphibia Grun.	1	0.023	0.001	2.094	0.049
N. angustata var. *acuta* Grun.	1	0.047	0.000	4.189	0.044
N. bacata Hust.	39	3.956	0.107	46.077	1.374
N. confinis Hust.	60	4.026	0.120	18.850	0.746
N. dissipata (Kütz.) Grun.	16	0.535	0.016	8.378	0.248
N. fonticola Grun.	75	14.032	0.389	54.454	2.358
N. frustulum (Kütz.) Grun.	9	0.977	0.047	27.227	1.241
N. gracilis Hantz.	5	0.209	0.006	4.189	0.131
N. kutzingiana Hilse	36	3.933	0.107	43.982	1.148
N. linearis Wm. Smith	11	0.326	0.008	4.189	0.130
N. luzonensis Hust.	1	0.023	0.000	2.094	0.026
N. palea (Kütz.) Wm. Smith	75	17.127	0.493	104.720	3.639
N. paleacea Grun.	3	0.256	0.006	14.661	0.348
N. recta Hantz.	17	0.582	0.025	8.378	0.993
N. romana Grun.	1	0.023	0.000	2.094	0.022
Nitzschia sp. #1	18	0.791	0.026	14.661	0.423
Nitzschia sp. #8	1	0.070	0.002	6.283	0.142
Nitzschia sp. #9	13	2.653	0.094	64.926	2.256
Nitzschia spiculoides Hust.	9	0.559	0.024	16.755	0.542
Nitzschia spp.	75	20.060	0.583	113.097	4.049
Nitzschia sublinearis Grun.	2	0.093	0.003	6.283	0.264
N. tryblionella Hantz.	2	0.047	0.001	2.094	0.068
Opephora sp.	1	0.023	0.000	2.094	0.035
Plagiotropis lepidoptera var. *proboscidea* (Cl.) Reim.	1	0.023	0.001	2.094	0.049
Rhizosolenia eriensis H. L. Smith	57	12.520	0.289	81.681	1.859
R. gracilis H. L. Smith	48	5.329	0.179	46.077	1.707

(continued).

APPENDIX TABLE 1 (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Rhoicosphenia curvata (Kütz.) Grun.	2	0.047	0.001	2.094	0.035
Skeletonema potamos (Weber) Hasle	5	0.535	0.007	31.416	0.335
Skeletonema sp.	3	0.209	0.003	12.566	0.131
Skeletonema spp.	7	0.791	0.019	35.605	0.853
Stephanodiscus alpinus Hust.	59	9.145	0.294	69.115	1.989
S. binderanus (Kütz.) Krieger	4	0.396	0.013	18.850	0.614
S. hantzschii Grun.	42	2.769	0.081	20.944	1.387
S. minutus Grun.	85	29.438	1.034	154.985	9.926
S. niagarae Ehr.	3	0.070	0.002	2.094	0.073
Stephanodiscus sp. #5	3	0.070	0.002	2.094	0.065
Stephanodiscus sp. #6	1	0.023	0.001	2.094	0.049
Stephanodiscus sp. #8	2	0.047	0.001	2.094	0.087
Stephanodiscus sp.	2	0.047	0.001	2.094	0.060
Stephanodiscus spp.	39	2.583	0.078	33.510	1.047
Stephanodiscus subtilis (Van Goor) A. Cl.	38	4.235	0.186	94.248	6.716
S. tenuis Hust.	22	0.861	0.028	10.472	0.746
Surirella augusta Kütz.	14	0.489	0.016	8.378	0.262
S. biseriata var. *bifrons* (Ehr.) Hust.	1	0.023	0.001	2.094	0.066
S. ovata Kütz.	1	0.023	0.001	2.094	0.073
S. ovata var. *africana* Hust.	1	0.047	0.001	4.189	0.133
Synedra delicatissima var. *angustissima* Grun.	27	1.838	0.060	14.661	0.528
S. filiformis Grun.	85	36.861	0.953	297.404	9.368
S. minuscula Grun.	67	16.080	0.484	94.248	2.749
S. ostenfeldii (Krieger) A. Cl.	52	8.843	0.309	50.265	2.219
Synedra spp.	8	0.233	0.007	4.189	0.228
Synedra ulna var. *chaseana* Thomas	33	12.450	0.409	75.398	3.327
Tabellaria fenestrata (Lyngb.) Kütz.	13	1.443	0.043	41.888	1.206
T. flocculosa var. *linearis* Koppen	82	121.893	2.254	927.816	10.886
Undetermined centric diatom sp. #1	22	16.546	0.468	314.159	8.322
Undetermined centric diatom spp.	9	0.814	0.028	14.661	0.796
Total for Division (160 species)		876.994	22.509		
CHRYSOPHYTA					
Chrysococcus dokidophorus Pasch.	38	3.467	0.096	23.038	0.719
Dinobryon cysts	66	6.888	0.203	48.171	1.500
D. divergens Imhot	35	15.661	0.337	217.817	3.665
Dinobryon sp.	12	1.838	0.050	35.605	0.964
Dinobryon spp.	63	12.008	0.372	136.136	3.382

(continued).

APPENDIX TABLE 1 (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Mallomonas pseudocoronata Presc.	29	1.559	0.040	12.566	0.569
Mallomonas sp.	3	0.209	0.006	14.661	0.427
Mallomonas spp.	3	0.163	0.003	10.472	0.151
Ochromonas sp. #4	31	15.778	0.378	337.197	10.502
Ochromonas sp.	1	0.023	0.001	2.094	0.060
Ochromonas spp.	89	147.793	3.561	1145.633	27.187
Spiniferomonas sp.	1	0.023	0.001	2.094	0.073
Tribonema spp.	1	0.186	0.008	16.755	0.697
Uroglenopsis spp.	1	0.698	0.029	62.832	2.641
Total for Division (14 species)		206.297	5.084		
CRYPTOPHYTA					
Chroomonas spp.	89	68.602	1.672	196.873	4.578
Cryptomonas marssonii Skuja	22	1.280	0.025	18.850	0.624
C. ovata Ehr.	90	28.647	0.678	98.436	2.766
Cryptomonas sp.	1	0.023	0.000	2.094	0.026
Cryptomonas spp.	60	5.282	0.131	23.038	0.760
Rhodomonas minuta Skuja	90	150.656	3.408	846.135	16.515
R. minuta var. *nannoplanctica* Skuja	34	8.540	0.266	83.776	3.442
Total for Division (7 species)		263.031	6.180		
PYRROPHYTA					
Ceratium hirundinella (O. F. Mull.) Shrank	7	0.186	0.004	4.189	0.086
Ceratium sp.	5	0.116	0.003	2.094	0.061
Glenodinium sp.	2	0.070	0.002	4.189	0.143
Glenodinium spp.	2	0.047	0.001	2.094	0.061
Gymnodinium sp.	10	0.465	0.009	12.566	0.245
Gymnodinium sp.	1	0.023	0.001	2.094	0.061
Gymnodinium spp.	3	0.163	0.004	6.283	0.181
Peridinium sp.	22	1.094	0.023	18.850	0.495
Peridinium spp.	42	5.608	0.200	41.888	2.635
Unidentified dinoflagellate sp.	22	1.745	0.037	23.038	0.573
Unidentified dinoflagellate spp.	7	0.419	0.013	8.378	0.228
Total for Division (11 species)		9.937	0.298		

(continued).

APPENDIX TABLE 1 (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
EUGLENOPHYTA					
Phacus sp.	1	0.023	0.001	2.094	0.066
Total for Division (1 species)		0.023	0.001		
UNDETERMINED					
Undetermined haptophyte sp. #1	85	292.841	8.793	1866.105	56.974
Undetermined haptophyte sp. #2	80	16.173	0.447	106.814	3.380
Undetermined colony sp. #2	34	20.688	0.529	134.041	4.597
Undetermined flagellate spp.	88	229.242	4.912	772.831	13.503
Total for Division (4 species)		558.944	14.681		

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-905/3-79-001	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Phytoplankton Assemblages of the Nearshore Zone of Southern Lake Michigan		5. REPORT DATE March 1979 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Eugene F. Stoermer & Marc L. Tuchman		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Great Lakes Research Division University of Michigan Ann Arbor, Michigan 48109		10. PROGRAM ELEMENT NO. 2 BA 645 11. CONTRACT/GRANT NO. Grant - R005337-01
12. SPONSORING AGENCY NAME AND ADDRESS Great Lakes Surveillance & Research Staff Great Lakes National Program Office U.S. Environmental Protection Agency Chicago, Illinois 60605		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA - GLNPO Great Lakes National Program Office

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Phytoplankton samples from nearshore stations along the Indiana coast of Lake Michigan were analyzed to determine the composition and seasonal abundance of phytoplankton populations. Occurrence patterns of major populations and population groups were inspected. As might be expected in a local inshore region where physical mixing and advection processes are relatively intense, phytoplankton distribution is highly variable. The largest general effect noted is a continuing increase in groups other than diatoms, apparently as a result of silica depletion. The singular exception to this trend is the abundant occurrence of Cyclotella comensis, a diatom which has only recently become abundant in Lake Michigan and can apparently tolerate very low silica levels. Specific to the region is an atypically high abundance of members of the diatom genus Nitzschia during some sampling periods. High abundance of these organisms appears to be associated with organic nitrogen and ammonia inputs. Occasional occurrences of populations such as Thalassiosira sp. and Skeletonema spp. were noted and may be indicative of local areas of high conservative ion input. Another characteristic of the phytoplankton assemblages in the Indiana nearshore region is the high abundance of microflagellates, especially organisms which apparently belonging to the Haptophyceae or Prasinophyceae.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
phytoplankton populations water quality, microflagellates, monitoring, nitrogen, phosphorus, silica	Southern Lake Michigan Indiana Nearshore	
18. DISTRIBUTION STATEMENT Available through NTIS Springfield, VA 22161	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 89
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

U.S. GOVERNMENT PRINTING OFFICE 826-681